Physical Education

Teaching Resource

FELTHAM PRESS

Physical Education

Contents List

Part 1 Mechanics
A Linear Motion
B Forces and Newton's Laws
C Impulse, Net Force & Projectile Motion
D Angular Motion

Part 2 Differences in Fitness Measures
A Training Effects
B Differences in Fitness Measures between Groups

Part 3 Energy Concepts
A Energy Sources
B Muscle Fatigue
C ATP-PC System
D Lactate Anaerobic System
E Aerobic Systems

Part 4 Performance Criteria
A Excess Post-exercise Oxygen Consumption
B Maximum Oxygen Consumption
C Lactate Threshold

Part 5 Motor Units and Control
A Types of Muscle Fibre
B Motor Units
C Proprioceptors and Kinaesthetic Feedback

Part 6 Individual Differences
A Personality Theories and Testing
B Achievement Motivation
C Attitudes
D Aggression
E Arousal
F Self Efficacy
G Attribution Theory

Part 7 Optimising Performance
A Anxiety and Goal Setting
B Social Facilitation
C Social Learning

Part 8 Groups
A Group Dynamics
B Leadership

Guidelines

Teaching Pack	Learning Unit	
1 Mechanics	**A Linear motion**	Understanding of the concepts of velocity and acceleration;
	B Forces and Newton's Laws	Newton's Laws of Motion applied in sporting contexts, to include the idea of force, inertia and momentum.
	C Impulse, Net force, Projectile motion	Application of forces in sporting activities, e.g. sprinting to demonstrate concept of impulse; high jump to demonstrate concept of net forces and shot putting to demonstrate concept of projectile motion.
	D Angular motion	Concept of angular momentum and its conservation during flight. Moment of inertia, and its relationship with angular velocity as shown during somersaulting and spinning.

Teaching Pack	Learning Unit	
2 Differences in fitness measures	**A Training effects**	Short and long-term effects of exercise. Planning training regimes for elite individuals. Specialisation of general training theory. Periodisation. Altitude training. PNF. Adaptive responses.
	B Differences in fitness measures between groups	Differences in fitness measures between a normal person and a trained athlete. Differences in fitness measures between males and females. Structural and physiological differences between males and females. **Teaching Pack Learning Unit Specification content**
3 Energy concepts	**A Sources of energy concepts**	Energy sources - fats and carbohydrates and their location within the body.
	B Muscle fatigue	Effects of intensity and duration of exercise on the use of sources of

energy; glycogen depletion and loading. Reference to muscle fatigue. Temperature and water regulation during exercise

	C ATP-PC system	The effectiveness of the phosphocreatine system.
	D Lactate anaerobic system	The effectiveness of the lactic anaerobic pathway. The regeneration of ATP by energy released from the anaerobic breakdown of glycogen and glucose;
	E Aerobic systems	The effectiveness of the aerobic pathways. The regeneration of ATP by energy released from the aerobic breakdown of glycogen, glucose fatty acids and glycerol; location of mitochondria, their central role in aerobic pathways.

Teaching Pack	Learning Unit	
4 Performance criteria	**A Excess post-exercise oxygen consumption**	Oxygen deficit during exercise; EPOC (oxygen debt) including the fast (alactic recovering) and slow (lactic recovery) components.
	B Maximum oxygen consumption	Significance of maximum oxygen consumption in sporting performance through practical examples; response to aerobic training.
	C Lactate threshold	Inefficiency of the lactate anaerobic system and the accumulation of lactic acid as a consequence. Relation to OBLA and lactate threshold, and the significance of these relationships to sporting performance.

Teaching Pack	Learning Unit	
5 Motor units and control	**A Types of muscle fibre**	Motor units and muscle fibre types, range of types in differing sports performers and as predictors of performance.
	B Motor units	Motor unit types, innervation, variations in the strength of the muscle response, spatial summation (multiple unit summation) and wave summation.
	C Proprioceptors and kinaesthetic feedback	Muscle spindle apparatus function, the stretch reflex, role in control of muscle contraction, anticipation of muscle loading.

Teaching Pack	Learning Unit	
6 Individual differences	**A Personality theories and testing**	Personality and its relationship to performance in sport. An understanding of the limitations of trait theory in relation to participation and performance. An understanding of the interactionist theory of personality in relation to personal and performance development. Use of personality tests. Mood states and the iceberg profile
	B Achievement motivation	Achievement motivation. Motives to achieve or avoid failure. Characteristics of each. Factors affecting the adoption of motives.
	C Attitudes	Attitudes and their importance in sport. Cognitive, affective and behavioural components of attitudes. Influences on the formation of attitudes - socialisation, peer and family influences, conditioning. Influences of prime socialising agents. Attitudes as predictors of behaviour. Changing attitudes - cognitive dissonance, persuasive communication; ways of measuring attitudes.
	D Aggression	Aggression and its relationship with all aspects of sport and theories of aggression. Instinct Theory. Frustration aggression; Social Learning Theory. Sport as catharsis; channelled / instrumental aggression and strategies to control reactive aggression; differences between aggressive and assertive behaviour.

	E Arousal	Arousal theory - arousal and its relationship to performance including types of activity, level of expertise and the personality of the performer. Arousal and attentional narrowing. Catastrophe Theory.
	F Self efficacy	Self-efficacy. Determinants and changes in self-efficacy.
	G Attribution theory	Attribution Theory - use Weiner's Model. The link between attribution and task persistence and level of performance. Characteristics of model and its application to sporting situations. Attributional retraining. Learned helplessness – characteristics and causes. Strategies to combat the adoption of learned helplessness.

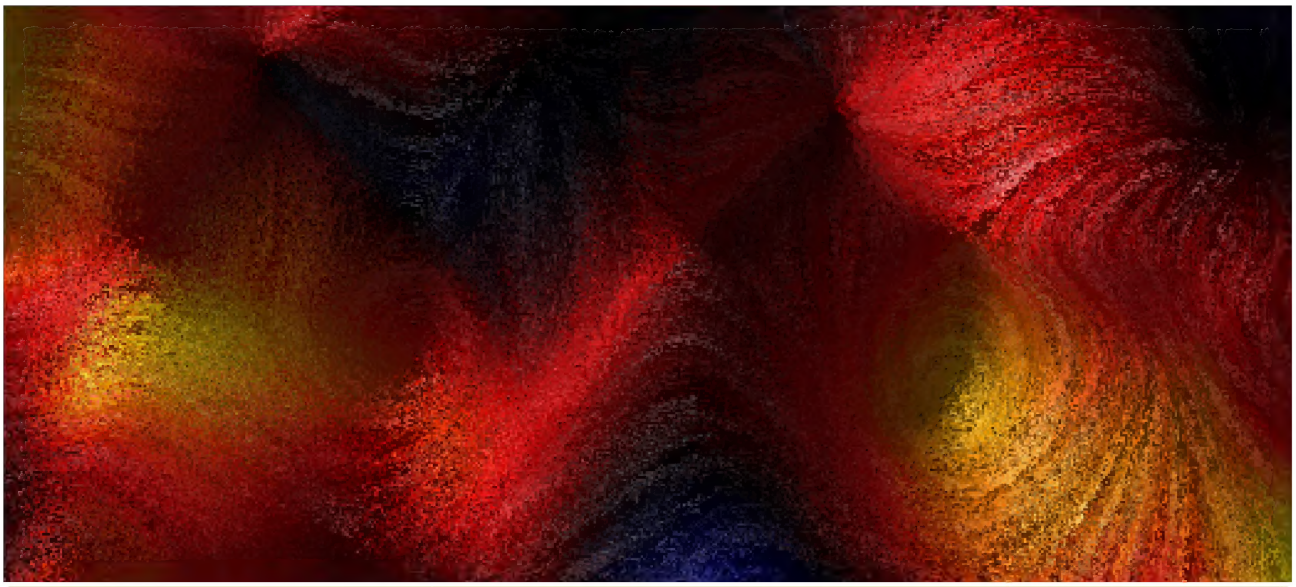
Teaching Pack	**Learning Unit**	
7 Optimising performance	**A Anxiety & Goal Setting**	Anxiety - state and trait, SCAT test, somatic and cognitive anxiety. Imagery and mental rehearsal, relaxation techniques, biofeedback. The positive and negative implications of stress for sports performance. Causes of stress. Stress implications for optimal performance; burn out; stress measurement and its validity. Stress reduction. Stress management. Improving self-confidence. Goal setting. Types of goals. Factors affecting goal setting. Methods and principles of goal setting.
	B Social facilitation	Social facilitation - effects of an audience and co-actors. Relationship with arousal levels. Effects of different levels of performance and for different types of task. Cottrell and evaluation apprehension.
	C Social learning	Motivational and co-ordination factors affecting the productivity/effectiveness of a group. Potential/actual productivity. The Ringlemann effect, social loafing and its relationship to sport. Strategies to overcome social loafing.

Teaching Pack	Learning Unit	
8 Groups	**A Group dynamics**	Groups and their dynamics related to sport performance. The team as a group. Group formation and dynamics. Cohesiveness of a group and Carron's antecedents. Co-operation and competition.
	B Leadership	Leadership - Definitions and the importance of leadership in sporting situations. Qualities associated with leaders. Types of leader - authoritarian, democratic and laissez-faire. Leadership - Nature versus nurture? - Great Man Theory and Social Learning Theory. Leadership - Other factors affecting it, e.g. situation and group members. Fiedler's Contingency model. Chelladurai's multi-dimensional model. The effectiveness of different types of leader.

Teaching Resource

Part 1 Mechanics

A Linear Motion



Introduction

Introducing mechanics to students with little or no background in physics and/or little or no confidence in their mathematical capability can initially appear quite daunting.

The essence of this resource is to relate biomechanics to everyday observations and to reduce the mathematical content as much as possible. For this reason, the teacher should aim to be the primary provider of mathematical calculation answers. The students should simply be following the process. Complex (or even simple) calculations should not be given to reinforce. Rather they appear to confuse and simply become practice at using a calculator, which is not the intention of the specification at all.

Students will be familiar with many of the mechanical terms required of them. The big problem will be that many of them will have been misused and/or misunderstood. It is important that terms are used correctly, and there is much to be said for the provision and/or development of a glossary.

General Considerations and Objectives

1 To allow students to understand and use appropriate terminology to describe linear motion

2 To enable students to appreciate the essential mechanical parameters that are apparent during performance

Tasks

In this study pack you will find a range of tasks that require the students to develop their knowledge of the terms and relationships involved in describing linear motion.

Students will need to

1. Understand the essential differences between everyday terminology and that used to describe linear motion
2. Use these terms to describe the performance of an athlete
3. Appreciate the difference between scalars and vectors

All the tasks involved require the students to work either from the tasks as free-standing units, or to use the tasks as additional reinforcement and/or revision to class-delivered lessons.

Assessment of this work could simply be as answers to the posed questions, or assessed as part of a group's work, or through class discussion.

Use the every day criteria that students are used to in order to describe linear motion; in essence, movement in a straight line.

Task 1

Consider a man running in a straight line. If the man runs 600 metres in 2 minutes, we can calculate his average speed, because:

Average speed = Distance covered ÷ Time taken

In this case, the man travelled 600 metres in 2 minutes. 2 minutes is the same as 120 seconds,

And hence his average speed = 600 ÷ 120 = 5.00 metres per second (ms^{-1})

a What would be the average speed of a man who jogged 600 metres in 3 minutes? Do this calculation in the space below:

3 mins is the same as 180 seconds

600 ÷ 180 = 3.33 ms^{-1}

Similarly, we can calculate the time taken to cover a distance, if we know the average speed.

Consider a man running at 4.00 ms^{-1}.

In 4 minutes (or 4 x 60 = 240 seconds), he will travel:

Average speed = Distance ÷ Time

Which can be rearranged into:

Distance = Time x Speed

= 240 secs x 4.00 ms^{-1}

= 960 metres

b How far would this man travel if he ran for;

i 10 minutes?:

10 mins is equivalent to 10 x 60 = 600 seconds

600 x 4.00 = 2400 metres

ii 21 minutes?:

21 min equals 21 x 60 = 1260 seconds

1260 x 4.00 = 5040 metres

Feltham Press

Task 1 *continued*

c How long would it take for the man to run 1000 metres if he is travelling at 5.00 ms^{-1}?

Time = Distance ÷ speed

Time = 1000 ÷ 5.00 = 200 seconds

= 3 mins and 20 seconds

d How far will a man travel if he walks for 12 minutes at 2.5 $m.s^{-1}$, and then realising he is late, runs for 5 minutes at 6 ms^{-1}?

12 mins is the same as 12 x 60 = 720 seconds

720 x 2.5 = 1800 metres

5 mins is the same as 5 x 60 = 300 seconds

300 x 6 = 1800 metres

he walks 1800 metres and runs 1800 metres - total

distance covered = 3600 metres

Task 2

Read the following materials, answering the questions in the spaces provided.

When describing linear motion however, we should use the word **velocity** to describe how fast a body moves.

Velocity is similar concept to speed, but includes the idea of "**direction**". In other words, any velocity takes place in a certain direction, and the concept of distance is replaced with that of **displacement**.

Displacement is the shortest straight line between the starting point and the finishing point.

Hence Average velocity = **Displacement** ÷ Time

So the average velocity for an athlete who runs 100 metres in 10 seconds is

Average velocity = Displacement ÷ Time

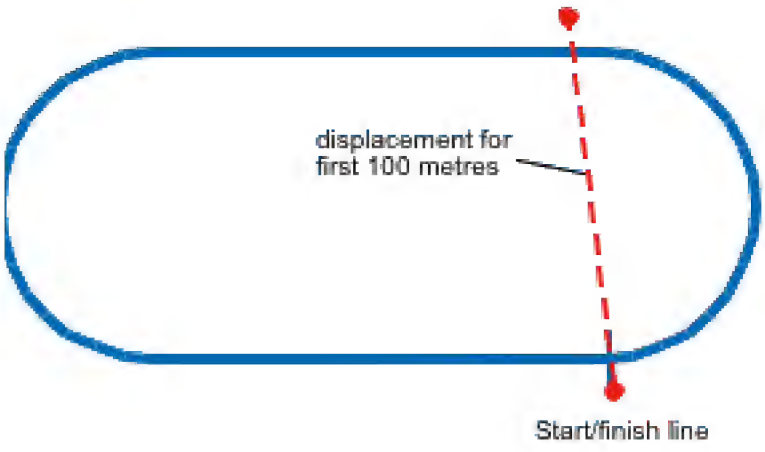
= 100 m ÷ 10 secs

= 10 ms^{-1}

But, if a runner on a 400 metre track, is running at a constant speed, then their velocity will alter as they move around the bends of the track.

This is because the displacement varies.

Thus if the athlete can cover each 100 metres of a 400 metre race in 15 seconds, the velocity of the runner over the first 100 metres will be equal to displacement ÷ time. The displacement would be equal to the straight line measured from the starting point to the finish point (100 metres in this case) as shown below:



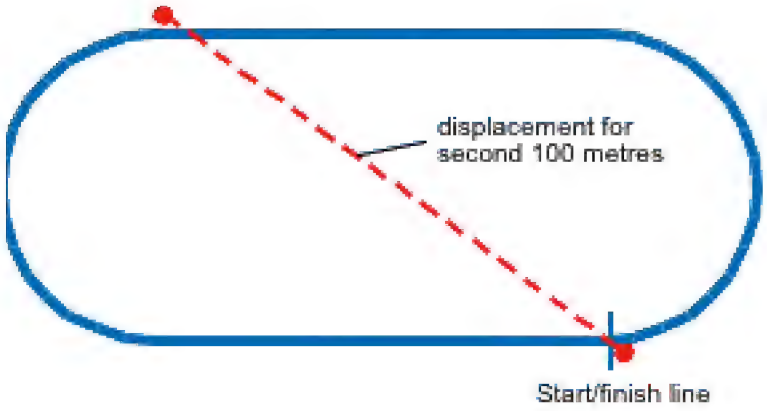
Task 2 *continued*

a If the displacement to the 100 metre point is 75 metres, what is the average velocity of the sprinter over the first 100 metres

velocity = displacement ÷ time

= 75 ÷ 15 = 5m.s^{-1}

For the first 200 metres, the average velocity would still be displacement ÷ time, but in this case the time would be 2 x 15 seconds = 30 seconds, and the displacement would be the measurement between the start and the 200 metre point as shown below:



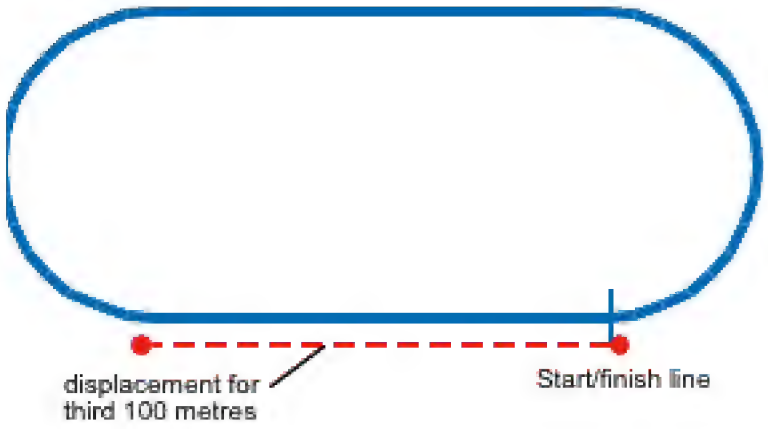
Task 2 *continued*

b If the displacement to the 200 metre point is 120 metres, what is the average velocity of the sprinter over the first 200 metres

velocity = displacement ÷ time

= 120 ÷ 30 = 4m.s $^{-1}$

For the first 300 metres, the average velocity would still be displacement ÷ time, but in this case the time would be 3 x 15 seconds = 45 seconds and the displacement would be the measurement between the start and the 300 metre point as shown below:



Task 2 *continued*

c If the displacement to the 300 metre point is 100 metres, what is the average velocity of the sprinter over the first 300 metres

velocity = displacement ÷ time

= 100 ÷ 45 = 2.2 m.s $^{-1}$

For the whole 400 metres, the average velocity would still be displacement ÷ time, but in this case the time would be 4 x 15 seconds = 60 seconds and the displacement would be the measurement between the start and the finish

d What is the average velocity of the sprinter over the whole of the 400 metre race

velocity = displacement ÷ time

displacement would be 0 (measurement from start to finish)

velocity = 0 ÷ 60 = 0 m.s $^{-1}$

Hence even running at a constant speed, average velocity varies because displacement varies

Task 3

Work through the following passages.

The average velocity for a 60 metre race can be a useful measure, but it becomes more accurate and provides more information, when velocities are taken for separate parts of an event.

For example, we can measure velocity during different stages of a 60 metre sprint on a track. Time keepers can be placed at 10 metre intervals down the track, and they can time how long it takes the athlete to reach the point opposite where they are standing from the starting point.

Make arrangements to complete this experiment now. You will need a subject who is willing to run, a starter and at least 6 timekeepers, each supplied with a stopwatch.

When the starter gives the 'go' command, all the timekeepers start their watches. Each timekeeper waits until the athlete passes their timing point before stopping their watch. If you have sufficient timekeepers and stop watches, have move than one timekeeper at different timing points and take the average time taken to reach that timing point.

The results of such an experiment can then be presented as a table that shows the time taken, and hence the average velocity, for each 10 metre section of the race.

After the experiment complete the table below:

Timing point	Distance covered	Time to point reach this point	Time taken for this 10m section (s)	Average velocity for each 10m section = displacement ÷ time
Start	0	0	0	0 ÷ 0 = 0
10 m	10 m			
20 m	10 m			
30 m	10 m			
40 m	10 m			
50 m	10 m			
60 m	10 m			

Task 3 *continued*

a In order to develop your understanding; continue the table below calculating the time taken for each 10 metre section, and then calculating the average velocity for that 10 metre section:

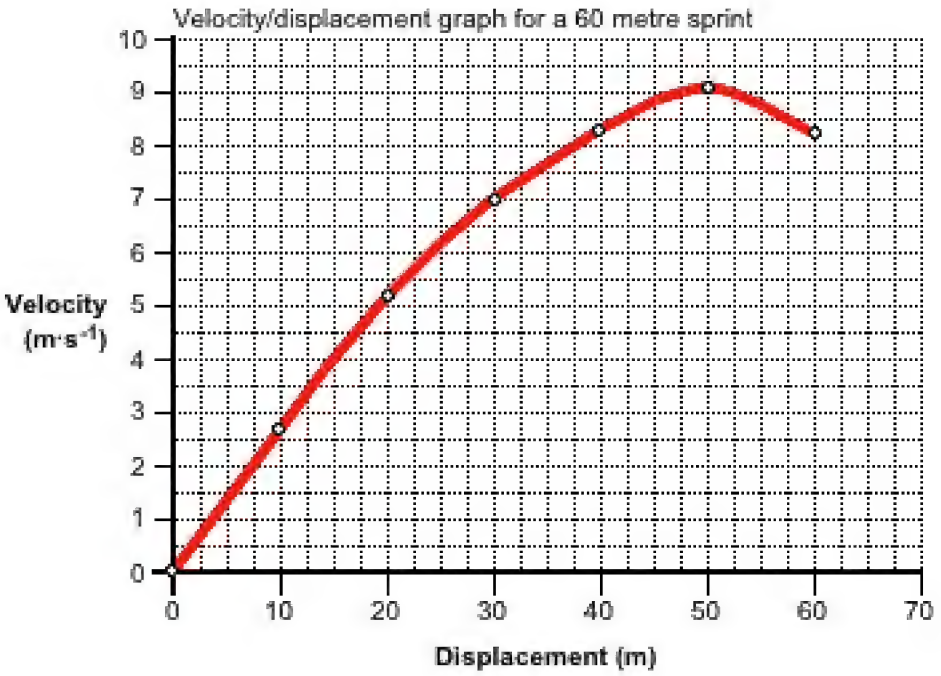
Timing point	Distance covered	Time to reach this point	Time taken for this 10m section (s)	Ave. velocity (ms^{-1}) for each 10m section = displacement ÷ time
Start	0	0	0	0 ÷ 0 = 0
10 m	10 m	3.7 s	3.7	10 ÷ 3.7 = 2.7
20 m	10 m	5.6 s	5.6 - 3.7 = 1.9	10 ÷ 1.9 = 5.2
30 m	10 m	7.0 s	*7.0 - 5.6 = 1.4*	*10 ÷ 1.4 = 7.1*
40 m	10 m	8.2 s	*8.2 - 7.0 = 1.2*	*10 ÷ 1.2 = 8.3*
50 m	10 m	9.3 s	*9.3 - 8.2 = 1.1*	*10 ÷ 1.1 = 9.1*
60 m	10 m	10.5 s	*10.5 - 9.3 = 1.2*	*10 ÷ 1.2 = 8.3*

Task 3 *continued*

b Draw a graph of these results, plotting distance on the x-axis and velocity on the y-axis.

If you look at the results of the velocities during the race, you should notice that they reach a peak at around the 50 metre mark, then begin to slow.

These changes can be partly related to the differing energy sources used during a 60 metre sprint.



Task 4

Work through the following, answering the questions posed.

You should have noticed in task 3 that velocities change during a sprint, they are not constant.

We call a change in velocity **acceleration**.

Acceleration may be defined as the **rate of change of velocity**.

It is possible to calculate acceleration:

$$\text{average acceleration} = \frac{\text{final velocity - initial velocity}}{\text{time}}$$

or $\text{acceleration} = (v_f - v_i) \div t$

Hence, considering our sprinter, we can use the results from the table to find their change in velocity over the 20-30 metre section, or their acceleration.

Thus velocity at 10 metres (v_i) = 2.7 ms^{-1}

velocity at 20 metres (v_f) = 5.2 ms^{-1}

time taken (t) = 5.6 – 3.7 = 1.9 secs

Hence average acceleration = (5.2 - 2.7) ÷ 1.9

= 1.3 ms^{-1} every second,
or 1.3 ms^{-2}

a Use the results from the table in Task 3a to calculate in the space below, the average acceleration between the 20 and 30 metre points, and between the 50 and 60 metre points:

Timing point	Time (s) taken for this section	Average velocity for each 10m section = displacement ÷ time (ms^{-})	Average acceleration for each 10m section $(v_f - v_i) \div t$ (ms^{-2})
Start	0	0	0
10 m	3.7	2.7	(2.7 - 0) ÷ 3.7 = 0.7
20 m	1.9	5.2	(5.2 – 2.7) ÷ 1.9 = 1.3
30 m	*1.4*	*7.1*	*7.1 - 5.2 ÷ 1.4 = 1.4*
40 m	*1.2*	*8.3*	
50 m	*1.1*	*9.1*	
60 m	*1.2*	*8.3*	*8.3 - 9.1 ÷ 1.2 = -0.7 ms^{-2}*

You should find that between the 50 and 60 metre points, the runner had a negative acceleration - he was slowing or **decelerating**.

Task 5

Velocity, acceleration and displacement all have **direction** as well as **magnitude** (size), and are called **vectors**.

Measurements such as speed, distance and temperature, which only have magnitude, are called **scalars**.

Because arrows also have direction and magnitude (length), it is possible and often useful, to represent vectors by arrows, using a scale to represent the magnitude, e.g., an arrow 10 cms long to represent a velocity of 10 ms^{-1}.

a Classify the following parameters as vectors or scalars:

time, velocity, temperature, displacement, direction, speed, distance, acceleration

scalars – time, temperature, direction, speed, distance

vectors – velocity, displacement, acceleration

Task 6

a Provide definitions for each of the following parameters:

Displacement *The shortest straight line between the starting point and the finishing point.*

Velocity *Rate of change of displacement in a given direction/displacement over time*

Acceleration *Rate of change of velocity/change in velocity divided by time taken to change*

Vector *Parameter/measure that has both magnitude/size and direction*

Scalar *Parameter/measure that has only magnitude/size*

Deceleration *Negative rate of change of velocity/change in velocity divided by time taken to change that produces a negative answer*

Speed *Rate of change of distance/distance over time*

Teaching Resource

Part 1 Mechanics

B Forces and Newton's Laws

General Considerations and Objectives

The concept of what is a force may appear simplistic, but because of the very nature of the earth, understanding all that is involved in the term force can be quite difficult, as forces are all around us and invariably act without being readily thought about.

1 To allow students to understand and use appropriate terminology to describe forces

2 To enable students to appreciate the essential mechanical parameters in terms of forces that are apparent during performance

3 To permit students to use knowledge of Newton's Laws of Motion in a performance setting

4 To allow students to appreciate at a simple level the idea of net forces

Tasks

In this study pack you will find a wide range of tasks that vary from the very simple to the quite complex, but the intention is to enable students to appreciate the nature of forces and the way in which Newton's Laws may be used to explain linear motion.

Students will need to

1. Understand the essential definition of a force
2. To understand and apply Newton's Laws to performance.
3. To appropriately use and apply mechanical terms

All the tasks involved require the students to work either from the tasks as free-standing units, or to use the tasks as additional reinforcement and/or revision to class-delivered lessons.

Assessment of this work could simply be as answers to the posed questions, or assessed as part of a group's work, or through class discussion.

Simple definitions of a force will not suffice when the term needs to be applied to the performance setting.

Task 1

Read through the following notes, answering the questions in the spaces provided.

Forces are what change a body's state of motion. If a performer or ball changes its state of motion from being at rest to moving, then this involves a force. Similarly if a performer or ball changes its direction, or slows, or even stops then a force caused that change in motion.

Forces are the "**push**" or "**pull**" that one body applies to another body, to affect its state of motion.

But not all forces are large enough to have these effects.

Consider a set of weights lying on the gym floor. Two weight lifters are taking turns, trying to lift the bar.

The weaker of the two weight lifters fails to lift the bar, but he was still applying a force to the barbell, trying to move it, whilst the stronger lifter managed to get the bar off the floor.

This gives us a better definition of a force:

A force is that which alters or tends to alter a body's state of rest or of uniform motion in a straight line.

a Think of a sport with which you are familiar, and imagine that sport taking place. Can you think of examples from that sport of a body's state of motion being changed, either from rest to moving (quickening), or from moving to rest (slowing), or the body's direction being changed? Having identified these examples, can you further identify what causes these changes in speed and direction?

Complete the table below, remembering that a "body" doesn't necessarily have to be the human body:

Activity *Team game*

	Example	**Cause of Change**
Change from moving to rest	*Stopping running*	*Muscles contracting*
Change from rest to moving	*Starting to run*	*Pushing off floor/using muscles*
Change in direction	*Side step*	*Pushing off floor*

Task 1 *continued*

Forces come in two types. Those that we ourselves generate, through contraction of our muscles; and those that come from outside our body.

We call the forces that muscles generate **internal forces**, whilst forces due to such things as air resistance, gravity and contact with the ground or some other body, are regarded as **external forces**.

b Forces are **vectors**, and as such have characteristics. What are the characteristics of vectors, and what do they mean?

magnitude (size) - Magnitude is a measure of how large the value is.

direction - Direction describes the way the force is directed.

point of application - The point of application of a force is the specific point where the force exerts its influence.

line of action - The line of action of a force can be described as the force's point of application, together with the direction of the force

Task 2

Read through the following notes, answering the questions in the spaces provided.

External forces include **gravity**, **air resistance** and **friction**. Newton's Law of Gravitation states that:

"**All particles attract one another with a force proportional to the product of their masses, and inversely proportional to the square of the distance between them**".

Realistically, the only object large enough to produce an observable effect on sports performers and performance is the earth. The force that results from these interactions with the earth is called **gravity**.

It is this force that causes objects that are thrown into the air, to be attracted back towards the planet's surface. The gravitational force that is acting on an object is called its **weight**. This is distinct from its **mass**.

Mass is the quantity of matter in a body, is usually measured in kilograms (kgs), and remains constant independent of gravity.

Weight is the effect of gravity on a body, and is equal to the mass of the body, multiplied by the acceleration given to that body by gravity, which is approximately 10 ms^{-2}. So that in the absence of gravity (i.e. in space) a body becomes 'weightless' but still has the same mass.

Thus the weight of a person who has a mass of 60 kgs:

Weight = mass x acceleration due to gravity

Weight = 60 kgs x10 ms^{-2}

= 600 Newtons

N.B. Newtons are units of force.

a What is the weight of a person who has a mass of 75 kg who is lifting a barbell of mass 60 kg?

weight = mass x gravity

mass = 75 + 60 = 135 kgs

weight = 135 x 10 = 1350 Newtons

b What does the weight of the same person become when he puts the barbell down?

weight = mass x gravity

mass = 75 kgs

weight = 75 x 10 = 750 Newtons

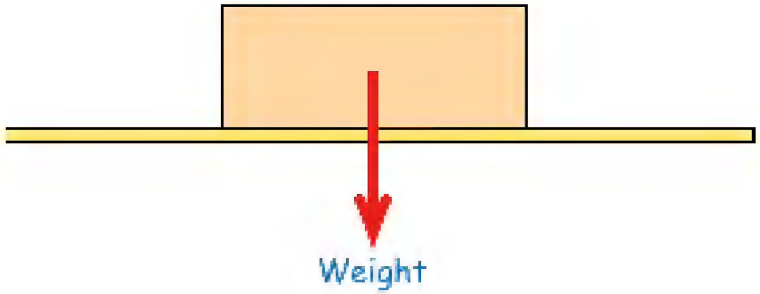
Task 2 *continued*

Whenever one object moves or tries to move over another, **friction** occurs as a force acting parallel to the surfaces in contact, which opposes the movement or tendency to move. In a 100 metre sprint, there is friction between the performer's running shoe and the track. The runner pushes against the track and a friction force is generated.

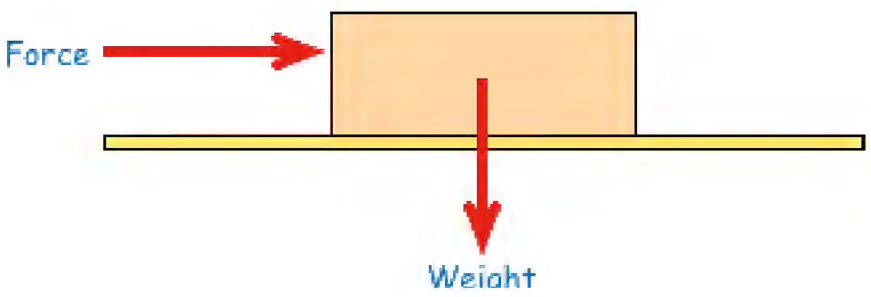
c Place a book on a level table. What forces are acting on the book. What is the name of this force?

The book is at rest and the only forces acting on the book are its weight. Note that there is also a reaction force from the table

d Draw a diagram of this situation, showing the book, the table and indicate the force(s) involved.



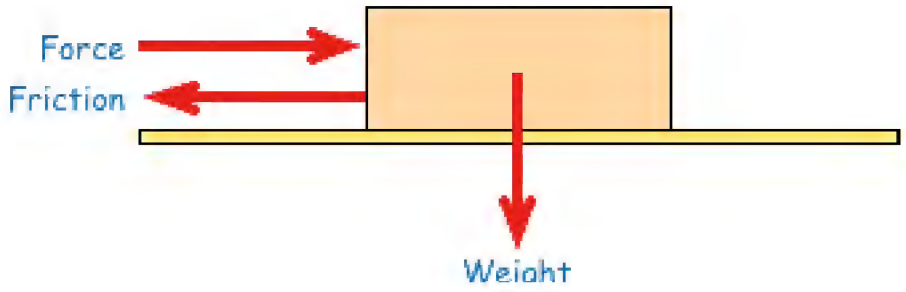
e Now apply a gentle force against the book that is insufficient to cause it to move. Draw a diagram to show this force being applied.



Task 2 *continued*

If the book is being pushed by a force, friction (the frictional force) will begin to operate, opposing the force of the push.

f Add friction as a force to your diagram.



Until such time as the book begins to move, this frictional force will be exactly equal to the pushing force. The frictional force that opposes motion has a value that depends on the weight of the book, and the degree of roughness between the book and the table, the two surfaces in contact. This degree of roughness is called the **co-efficient of limiting friction.**

Such that **F = μR**

Where F is the frictional force, μ is the co-efficient of limiting friction and R is the weight of the book. In the case of a sports performer such as a 100 metre sprinter, the co-efficient of limiting friction is what provides the grip between the athlete's running shoe and the ground to prevent slipping.

g What effect does increasing the weight of the book have on the frictional force?

Weight increases the frictional force

Friction is thus a contact force that acts between and parallel to the two surfaces in contact. It acts to oppose the motion between the contacting surfaces and is proportional to the weight force that pushes the two surfaces together.

The important thing about friction in terms of sport is that locomotion or movement requires frictional forces. For this reason the shoes you wear for sport decide to a large extent decide the degree of locomotion you can achieve. Shoe designers try to achieve as great a value for the co-efficient of friction as possible for most sports. In some sports, such as ice-skating and skiing, friction is meant to be minimised.

Air resistance is essentially friction due to air passing over surfaces.

Task 3

Read through the following notes, answering the questions in the spaces provided.

When a body is at rest, it is reluctant to do anything other than remain at rest. A heavy set of weights lying on the floor of a gym shows this resistance when attempts are made to move them. Similarly, when a body is moving, it is reluctant to change what it is doing.

Think of something heavy - a ten-pin bowling ball for example - imagine pushing it in order to get it to move. It's hard to get it going, but once it's moving, it's fairly easy to push. There is an initial reluctance by the ball to start to move.

Ever tried stopping a moving ten-pin bowling ball? Once the ball is moving, it is reluctant to change what it is doing. Imagine standing in front of a moving ten-pin bowling ball and trying to stop it with your hands - it takes a great deal of effort, and usually results in bruised fingers!

This reluctance of a body to change from the type of motion it has, is called **inertia**. This is the basic idea behind **Newton's First Law, the Law of Inertia.** This Law states that;

"**A body will remain in a state of uniform motion in a straight line (or remain at rest) unless compelled to change its state of motion by a net external force acting upon it**".

Inertia is not something that can be gained or lost. Inertia is a **reluctance to change**.

It is **mass** that determines inertia. Extra mass means a larger inertia, which in turn means that changes in speed and/or direction will be more difficult.

a Explain why it is easier to start or stop a bike than it is to start or stop a bus.

Because the bike has less mass or inertia, and therefore a smaller reluctance to change its state of motion.

This law clearly explains that the normal thing is for objects to continue travelling in a straight line with constant velocity. It also explains that if an object is changing velocity, either increasing or decreasing, and/or it is changing direction, then there must be a **net external force** acting upon it. Similarly, if an object is not changing its velocity, and/or direction, then the net forces acting upon it must be zero.

Task 3 *continued*

b This may seem to be at odds with what we all observe when we kick a football. No matter how hard we kick the ball, it always eventually slows down and stops. Try to explain this.

Friction and air resistance acts as net external forces to slow the ball

When we observe movement in real life, there are always forces acting upon an object, however small, and it can be difficult to appreciate Newton's First Law.

The following example might help.

Consider an ice-hockey puck at rest on the surface of the ice. As the puck's motion is not changing, then the net effect of all the forces acting on it must be zero.

An ice-hockey stick now hits the puck. During the short period of time that the stick is in contact with the puck, a force is applied to the puck, and the puck changes its state of motion from being at rest, to one of forward motion.

As soon as the contact between the stick and puck is over, the force causing the change of motion is no longer present, and the puck will travel across the ice in a straight line and with constant motion. (*You have to use your imagination and ignore the effects of friction between the ice and the puck, and air resistance between the puck and the air!*). In theory at least, this puck would continue travelling forever with constant velocity and in a straight line, until it is affected by another force.

This will happen when it hits the wall at the side of the rink. Whilst it is in contact with the wall, the puck experiences a force that changes its direction, and causes it to rebound with a new velocity. Once it leaves the sidewall, no forces are acting on the puck, and it continues to travel in a straight line with constant velocity.

In a similar way, Newton's First Law can be applied to the observed changes in the state of motion of a soccer ball when it is kicked.

Write in your own words, the effects of Newton's First Law on the following phases in kicking a soccer ball:

c Phase 1 - the ball is at rest on the floor

Ball at rest – no net forces acting - Mass determines inertia

Task 3 *continued*

d Phase 2 - the player's foot is in contact with the ball

Players foot exerts force on ball causing a change in the ball's motion from rest to moving. Direction of force applied by foot determines direction of motion of ball

e Phase 3 - the player's foot is no longer in contact with the ball. What should theoretically happen?

In theory the ball should continue to travel in a straight line with constant velocity

f What do we actually observe?

Ball slows down

g Why do we observe this?

Effects of friction

h Phase 4 - What happens to the ball when it hits another object?

Object applied a force causing the motion of the ball to alter - it changes velocity and direction

Task 3 *continued*

i Now consider a 100 metre sprinter in the set position on the blocks. Use Newton's First Law to explain this situation.

He is not moving, and therefore net forces must be zero

In order to leave the blocks; the sprinter must generate some force to change his state of motion from rest to forward motion.

Although the mechanism of how the sprinter generates forces may not as yet, be clear, it should now be obvious that some type of force is applied to the sprinter, as there is a rapid change in the sprinter's state of motion.

After the race, the runner rapidly slows and then stops. Again it should now be obvious that in order to achieve this change in motion the sprinter must again apply some force.

Note that the inertia of the sprinter remains the same throughout the race, because his mass has not altered, and hence his reluctance to change his state of motion remains constant.

Task 4

Read through the following notes, answering the questions in the spaces provided.

Every thing that is in motion, such as a swimmer, a sprinter, a tennis ball, or a bowling ball travelling down a lane, has a certain mass and a certain velocity. The product of these two values is known as its **momentum**. Momentum is:

"**The quantity of motion that a body possesses**".

Momentum = mass x velocity

If two objects, e.g. rugby players, are travelling with the same velocity, then the one with the greatest mass has the greater quantity of motion, or momentum.

Similarly if two objects have the same mass, then the one that is travelling with the greatest velocity has the greatest quantity of motion, or momentum.

Objects with high velocity, e.g. a downhill skier, or a large mass, e.g. a rugby scrum, will each have a large momentum. Newton's second law incorporates this concept. It states that:

"**The rate of change of momentum of an object (or acceleration of an object of fixed mass) is directly proportional to the force causing the change, and the resulting change in momentum takes place in the direction in which the force was applied**".

Linking this complex definition to Newton's First Law, it can be seen that a force is needed to change the momentum of an object. In most sports situations, the mass of the object's involved can be assumed to be constant, and therefore momentum is the same as velocity.

Hence, Newton's Second Law can be interpreted as the rate of change of velocity is directly proportional to the force causing the change.

Task 4 *continued*

a What do we call the rate of change of velocity?

Acceleration

Hence Newton's Second Law becomes:

"**The rate of acceleration is directly proportional to the force causing the change.**"

In other words, **F** (Force) = **ma** (mass x acceleration)

The important thing to notice from this equation, is that provided the masses involved remain constant, the observed acceleration of an object is proportional to the net force acting on the object at any particular time.

Note that an object is only accelerated whilst a force is being applied to it. When you kick a football, acceleration is only given to the ball while the foot is in contact with the ball.

b Use Newton's Second Law to explain how a sprinter leaves the starting blocks.

The sprinter applies a force to the blocks and the acceleration that he achieves from the blocks, depends of the magnitude of the forces that s/he can generate

Task 5

Read through the following notes, answering the question in the space provided.

Newton's Third Law states that:

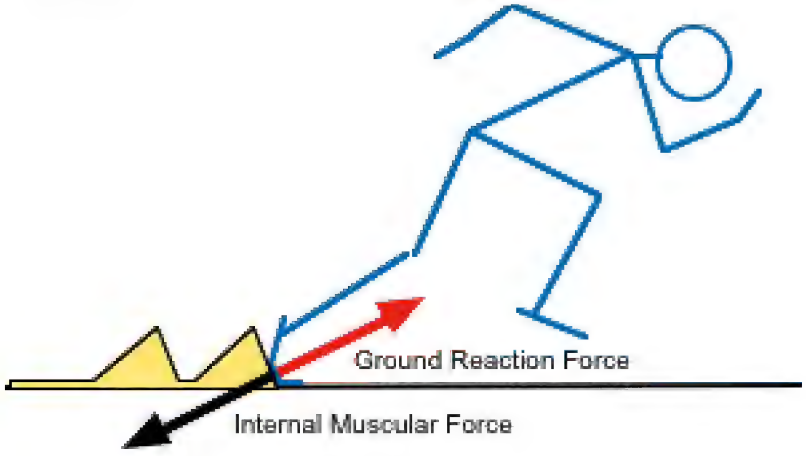
"**When an object exerts a force on a second object, there is a force equal in magnitude but opposite in direction, exerted by the second object on the first**".

This law is invariably called the law of **action/reaction**. In the sporting situation, the two objects concerned are often the performer and the ground.

Thus the sprinter on the blocks exerts a force on the blocks, and there is an equal, but opposite force driving the sprinter forwards, but as the blocks are attached to the earth, and the earth has such a large mass compared to that of the sprinter, the acceleration given to the earth by the sprinter is insignificant.

However the force given to the sprinter by the earth causes him to accelerate. This force is called the **ground reaction force**.

In much the same way, the soccer player who kicks the ball applies an **action force** to the ball, and simultaneously receives an equal and opposite **reaction force**, which can usually be felt on the foot.



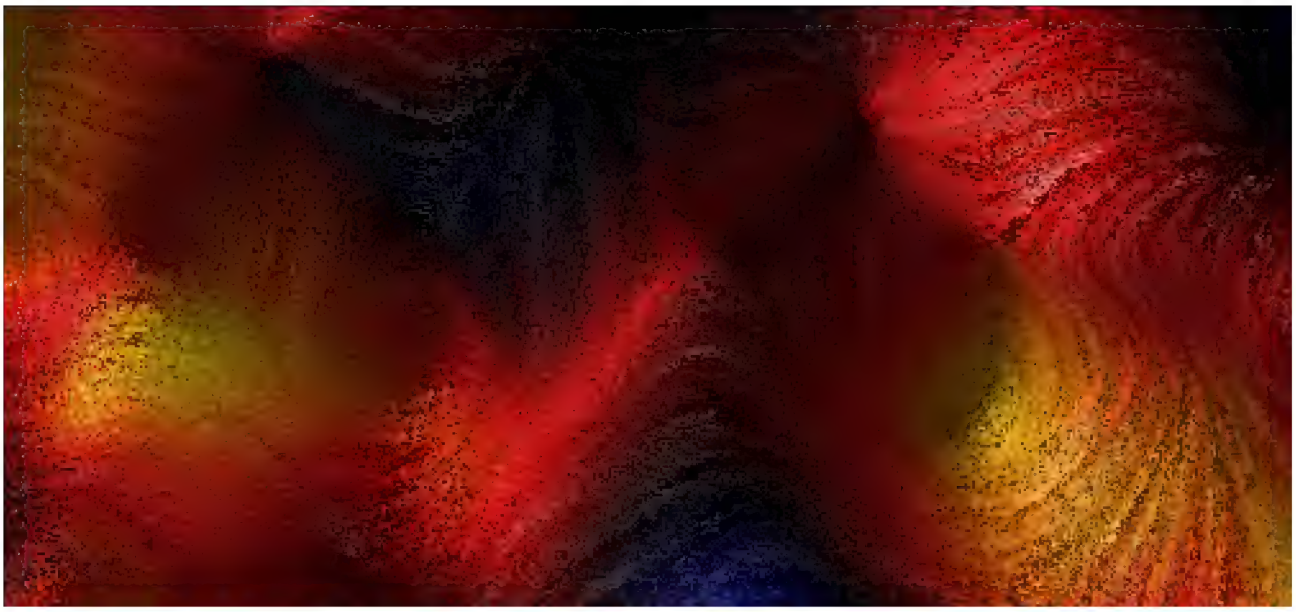
a Use Newton's Third law to explain how a sprinter leaves the starting blocks.

The sprinter applies a internal muscular force to the starting blocks which are attached to the earth. Newton's Third Law tells us that for every action force there is an equal and opposite reaction force, and therefore the earth exerts a reaction force against the sprinter which drives them off the blocks.

Teaching Resource

Part 1 Mechanics

C Impulse, Net Force and Projectile Motion



Feltham Press

General Considerations and Objectives

The concept of impulse is quite difficult to grasp, but if discussed in terms of the phases of a sprinting race then its application becomes quite obvious. In a similar vein, net forces can become quite complicated, especially when it comes to resolving forces. However the matter is simplified by admitting only to the existence of vertical forces as involved in high jumping. Projectile motion is complicated by air resistance, but here again the complication may be reduced by looking at a projectile when air resistance effects are minimised.

We are therefore left with three complicated mechanical concepts being explained in simple terms, which is exactly what this resource endeavours to do.

1. To allow students to understand and use appropriate terminology to describe impulse, net forces and projectile motion.
2. To enable students to appreciate the essential mechanical parameters that govern and are apparent during performance

.

Tasks

In this study pack you will find a limited range of tasks that attempt to make difficult constructs simple to understand. The intention is to enable students to appreciate the nature of impulse and the way in which impulse varies in activities such as sprinting. Similarly, an appreciation of the way vertical forces vary during vertical movements are considered, as are the horizontal and velocity components of, and factors affecting projectile motion.

Students will need to

1. Understand the concept of impulse and the way it varies during sprinting
2. Appreciate the way in which vertical forces vary during vertical movements
3. Name and describe the shape of a typical flightpath, and demonstrate how the horizontal and vertical velocity components vary during flight
4. Name and explain the three factors affecting the distance achieved during flight
5. To appropriately use and apply mechanical terms

All the tasks involved require the students to work either from the tasks as free-standing units, or to use the tasks as additional reinforcement and/or revision to class-delivered lessons.

Assessment of this work could simply be as answers to the posed questions, or assessed as part of a group's work, or through class discussion.

Theintention is to keep the mathematical requirements to a minimum, and this should be remembered, especially when considering impulse.

Task 1

Read through the following information, answering the questions in the spaces provided.

The push of the high jumper against the ground to generate a large vertical momentum in order to project themselves over the bar, and the push of the runner against the starting blocks to generate a large ground reaction force for his acceleration, both result in the generation of a large **impulse**.

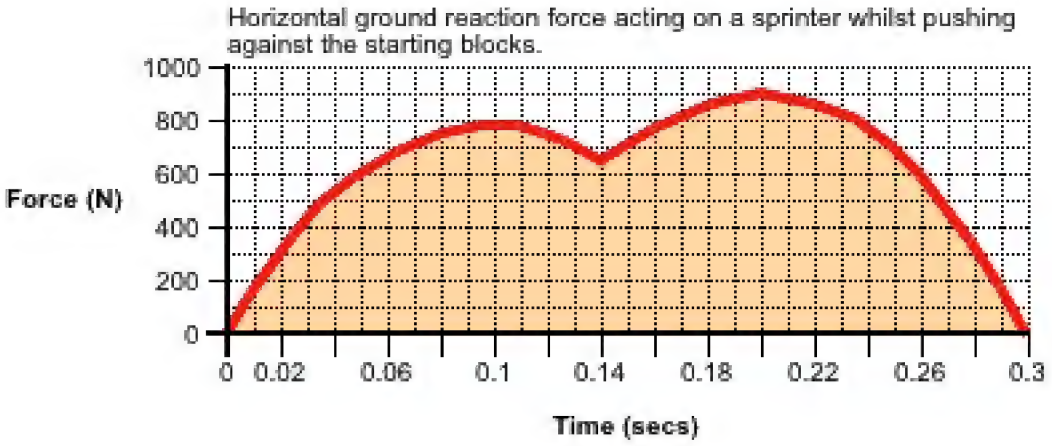
Impulse is **force x time**, and mathematically, it can be shown that for a body of constant mass, impulse is equal to **change in velocity**.

Impulse (f x t) equals change in velocity (v_f - v_i).

In practise, impulse is measured using pressure platforms, which detect the amount of force being applied during the time the foot is in contact with the ground.

The resulting data is usually represented graphically, with force on the y-axis and time on the x-axis. When this is done, the shaded area under the curve of the graph represents force multiplied by time.

Task 1 *continued*



a What do you understand by the term impulse and how is impulse related to velocity?

Impulse is force times time; impulse equates to change in velocity, which in turn equates to acceleration.

At the start of a 100 metre race, the runner pushes back against the starting blocks in order to generate a large ground reaction force.

b Explain what the above graph shows.

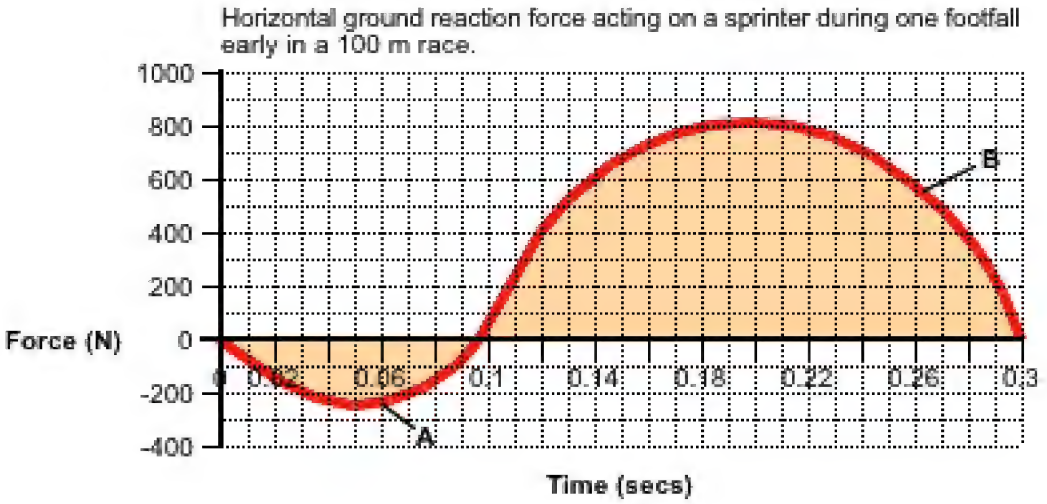
Impulse has two peaks. These correspond to the two main groups of muscles involved in pushing off the blocks - the gastrocnemius and the quadriceps

Impulse is related to horizontal velocity when running. Once having left the blocks, the athlete proceeds down the track. In terms of horizontal ground reaction forces (the one's we are interested in!) during the race, it is important to realise that as the foot makes contact with the ground, the reaction force is initially acting against the direction in which the athlete is running, and therefore has a negative value (think of it as the foot landing).

But as the body moves over the supporting foot, then the force acting on the runner becomes directed forward and impulse becomes positive. In other words during each footfall, there is an initial time period when the reaction force causes negative impulse, and then a later time when the reaction force causes a positive impulse.

Task 1 *continued*

Thus, during the early part of a race, impulse is like the graph below.



c Explain the apparent two different impulses labelled as A and B in the above graph.

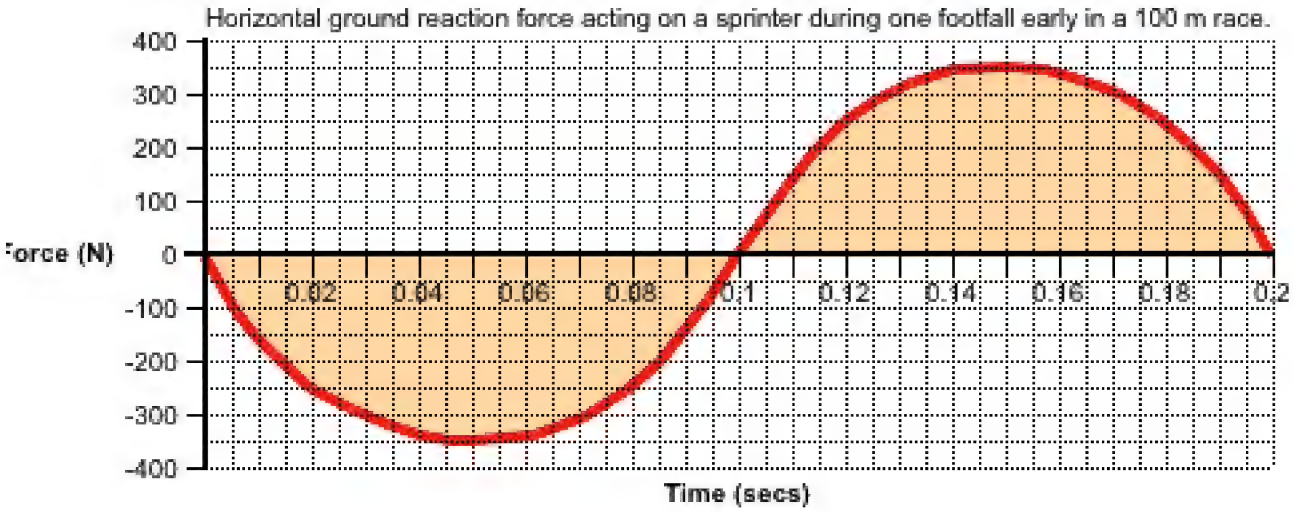
Impulse A is the negative impulse that arises as the foot lands, while impulse B is the positive impulse due to the foot pushing off the ground.

Net impulse, that is, positive impulse minus negative impulse, which is represented on the graph as the shaded area above the x-axis, minus the shaded area below the x-axis, is **positive** (the area above the x-axis is larger than the area below the x-axis).

As impulse has previously been shown to equal change in horizontal velocity, we can see that this must represent a positive change in velocity, in other words the runner is increasing their velocity, or accelerating.

The horizontal ground reaction forces acting on a sprinter during the middle stages of a sprint are shown overleaf.

Task 1 *continued*

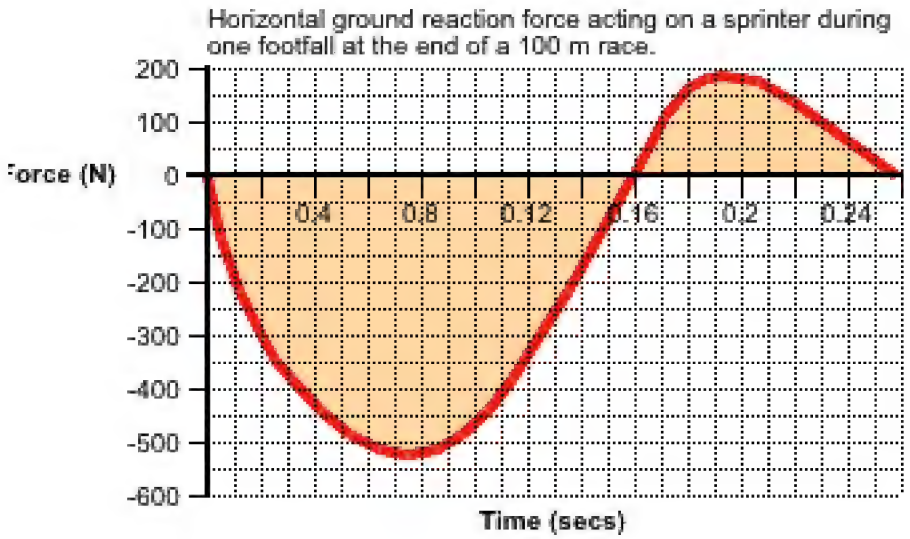


d Explain the situation concerning impulse as shown in the above graph.

Negative impulse is essentially equal to positive impulse. Hence there is a zero net impulse which must equate to a zero acceleration. In other words the athlete is running with constant velocity

Task 1 *continued*

The horizontal ground reaction forces acting on the sprinter towards the end of the race are shown below.



e Explain the situation concerning impulse as shown in the above graph.

Negative impulse larger than positive impulse. Hence there is a net negative impulse which must equate to a negative acceleration. In other words the athlete is running with decreasing velocity

f Suggest a physiological reason for the observed decrease in velocity at the end of a 100 metre sprint.

This is due to a deficit of suitable energy substrates, namely phosphocreatine

Task 2

Read through the following information, answering the questions in the spaces provided.

A sports performer is always acted upon by **two external forces** whilst he is in contact with the ground. The direction and magnitude of one of these forces, **gravity**, remains constant throughout any activity, because the mass of the objects involved, and their distance apart, effectively does not change. In other words the performer's **weight** (gravitational force) will not change.

The other force, the **ground reaction force**, varies considerably, depending on the way the body segments (limbs, trunk, head, etc) change their motion. The forces generated and transmitted to the ground, and the corresponding ground reaction force depends on the combined effect of all the masses and accelerations of the individual body segments.

By adjusting the timings and order of the acceleration of these segments (essentially his technique), the performer can vary the magnitude and direction of the ground reaction force he experiences. The highly skilled performer can generate optimal magnitude and direction for his ground reaction forces.

The relationship between these two forces, gravitational force and ground reaction force, can be illustrated by referring to activities such as a vertical jump, the take off during high jumping, or a squat. The mechanics of a squat will be described, but the principles apply to all vertical movements.

a Which muscles act as the agonists (prime movers) at the hip, knee and ankle during a squat?

Hip - hamstrings and gluteals; Knee - quadriceps; ankle - gastrocnemius

At the start of a squat, both gravitational force and the ground reaction force are acting upon the performer. If there is no movement up or down, these forces must be exactly equal and opposite in direction, and therefore the performer is experiencing net zero force, and his vertical velocity is zero.

If the performer is now moving down, his vertical velocity must have changed, and therefore a net external force must be acting. What in fact the performer has done, is to reduce the muscular force that he is applying to the ground, which in turn (Newton's Third Law) reduces the ground reaction force.

Now the gravitational force is greater that the ground reaction force, and hence the net force is acting in a downwards direction

Task 2 *continued*

b Describe in your own words the changes to the two vertical forces during the downward phase of a squat.

Gravitational force remains unchanged; Ground Reaction Forces decrease

c You can check this reduction in ground reaction force by standing on a set of bathroom scales, and then performing a squat - you should see an immediate change in the magnitude of your "weight" (sic).

As the performer nears the end of the downward squat phase, the jumper tenses the muscles in the leg that bring about extension.

d Which muscles cause extension at the knee?

Quadriceps

This increases the force being applied to the ground, and a corresponding increase in the ground reaction force, until the ground reaction force becomes greater than the gravitational force.

e Describe in your own words the changes to the two vertical forces during the upward phase of a squat.

Gravitational force remains unchanged; Ground Reaction Forces increase

The same principles apply to all vertical movements. Upward movements involve muscle contractions which generate a corresponding Ground Reaction Force that is greater than gravitational force, whereas downward movements involve a Ground Reaction Force that is less than gravitational force.

f What type of muscle contractions are involved in downward and upward movements?

Both isotonic; upward concentric; downward eccentric

Task 3

Take a video recording of pairs of students throwing a variety of ball to each other. Indoors is obviously better, and a wide angle, long range 'shot' works best. Keep the camera still and capture the whole of the flight of the balls.

Back in the classroom, play the tape back through a television using the slow-motion facility.

Place overhead projector acetates onto the TV screen, and use a suitable pen to mark the position of the ball at each frame.

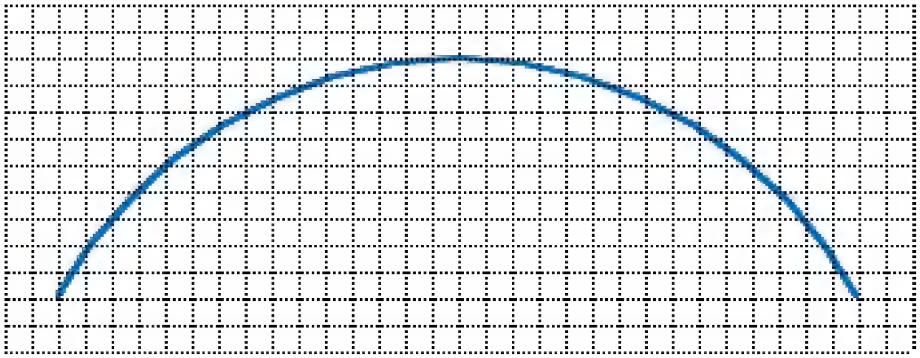
On completion you will have produced various points of the flightpath of the ball. Join up these points.

This flightpath is a **parabola**.

Task 4

Read through the following information, answering the questions in the spaces provided.

During flight, a ball (or high jumper) acts as a **projectile**, and like all projectiles, once in the air they follow a characteristic flight path as shown below.

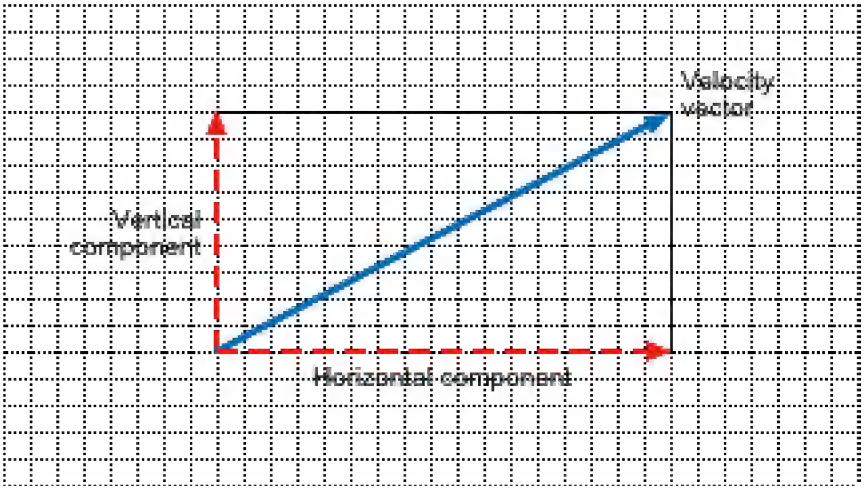


a What is the name given to this shape of flightpath?

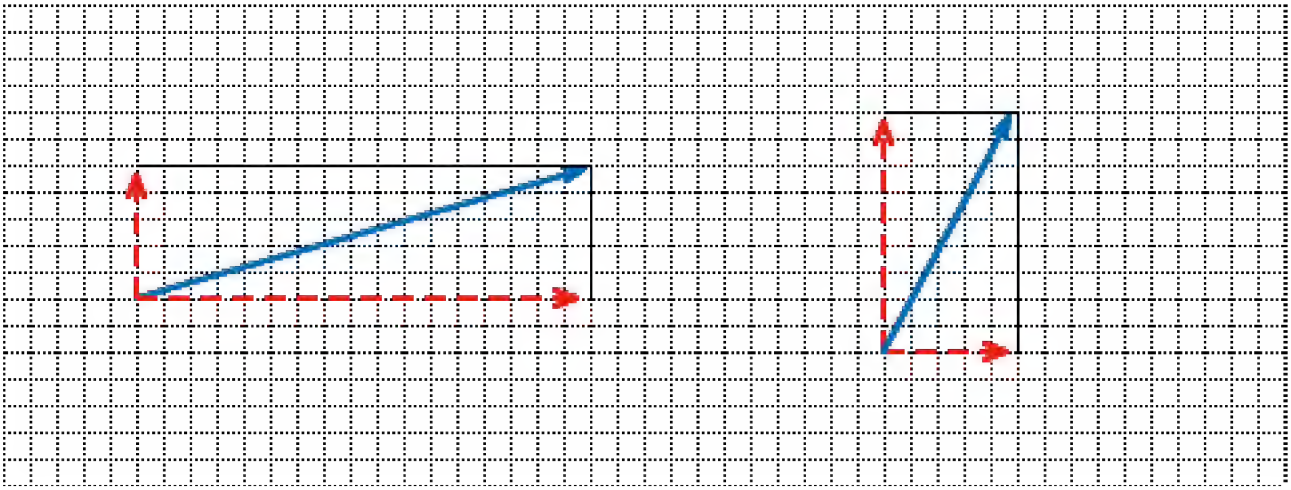
parabolic

Task 4 *continued*

The initial velocity that any projectile has can be divided into its two components, the **vertical component** and the **horizontal component**. This is done by simply making the velocity vector the diagonal of a rectangle, and the sides of the rectangle become the vertical and horizontal components.



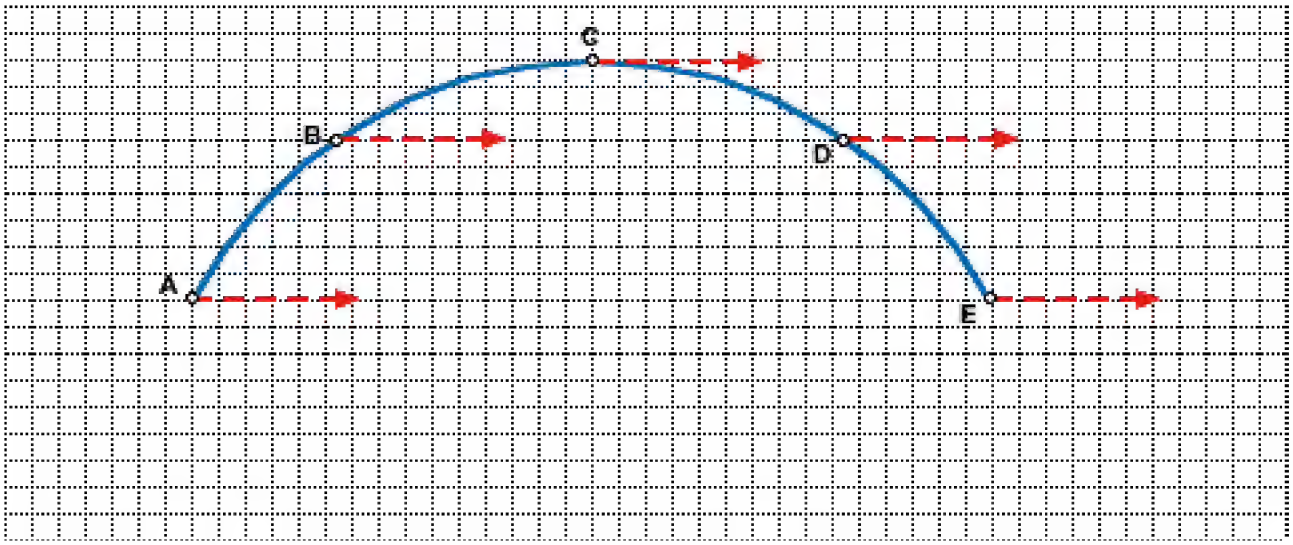
b Draw the vertical and horizontal velocity components on the following velocity vectors.



Task 4 *continued*

The reason why many projectiles follow a parabolic flight path is because there are no external forces acting on the ball's **horizontal** motion (friction or air resistance is so small it may be considered negligible), and so the horizontal velocity remains constant until it returns to the ground.

c Draw the horizontal velocity components at the five point indicated on the parabolic curve.



d Explain why the horizontal velocity component remains constant during the flight of a projectile such as the shot putt.

During flight the only factors affecting the horizontal velocity component of an object is air resistance (friction). In most cases, but especially in a shot putt, this may be considered negligible

The vertical velocity of the ball will be subject to the effects of gravity, and therefore the vertical component of velocity will be changing at the rate of 10 ms^{-1} for every second that it is in the air.

In other words the only force affecting a ball whilst it is in flight is **gravitational force**.

However the vertical velocity component of a projectile is affected by **gravity**, which acts in a downward direction which initially reduces the vertical velocity component and then later in the flight makes it negative:

Task 4 *continued*

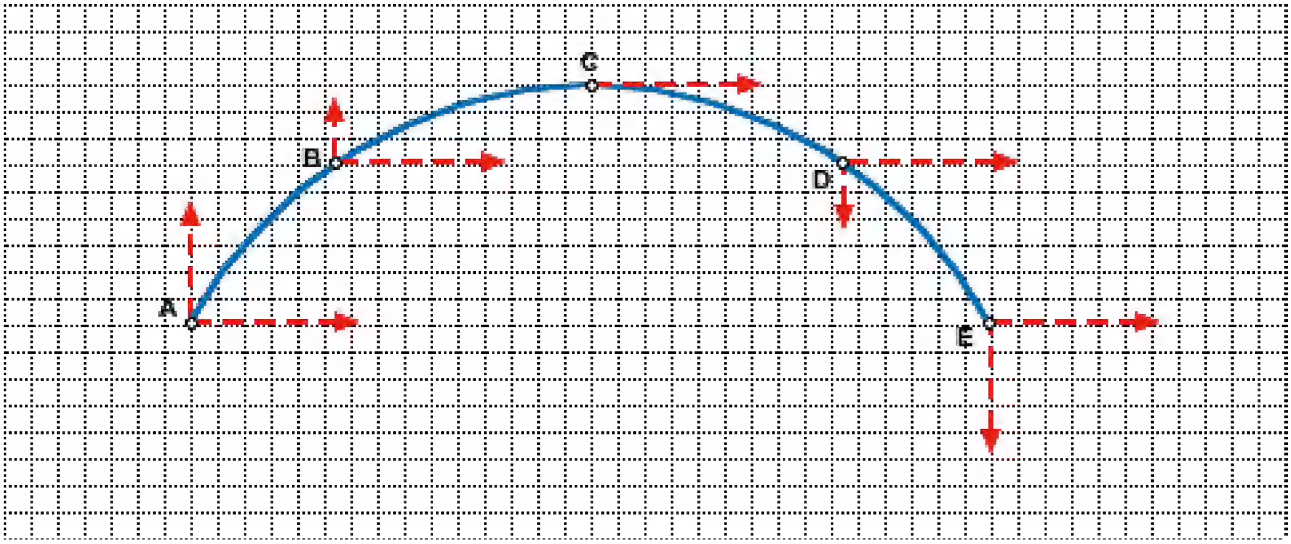
The same may be considered as true for many other projectiles such as the long jumper and the shot putt, and hence most projectile flights have the following characteristics:

- No horizontal forces (ignore air resistance),
- Parabolic flight path,
- Only gravitational forces affecting them.

e Explain why and how the vertical velocity component of a projectile varies during its parabolic flight.

The vertical velocity component varies during flight, depending on the effects of gravity. Gravity acts to decrease the vertical velocity component. This causes the vertical velocity component to initially reduce in size until it becomes zero and then decrease further to become negative

f Add the vertical velocity component to the flightpath shown below:



Note that the magnitude of the vertical velocity component is zero at the peak (apogee) of the parabola, and is equal and opposite to the initial value at the end of the parabola.

Task 5

Read through the following information, answering the questions in the spaces provided.

The distance travelled by a projectile is determined by three factors:

- Angle of release
- Speed of release
- Height of release

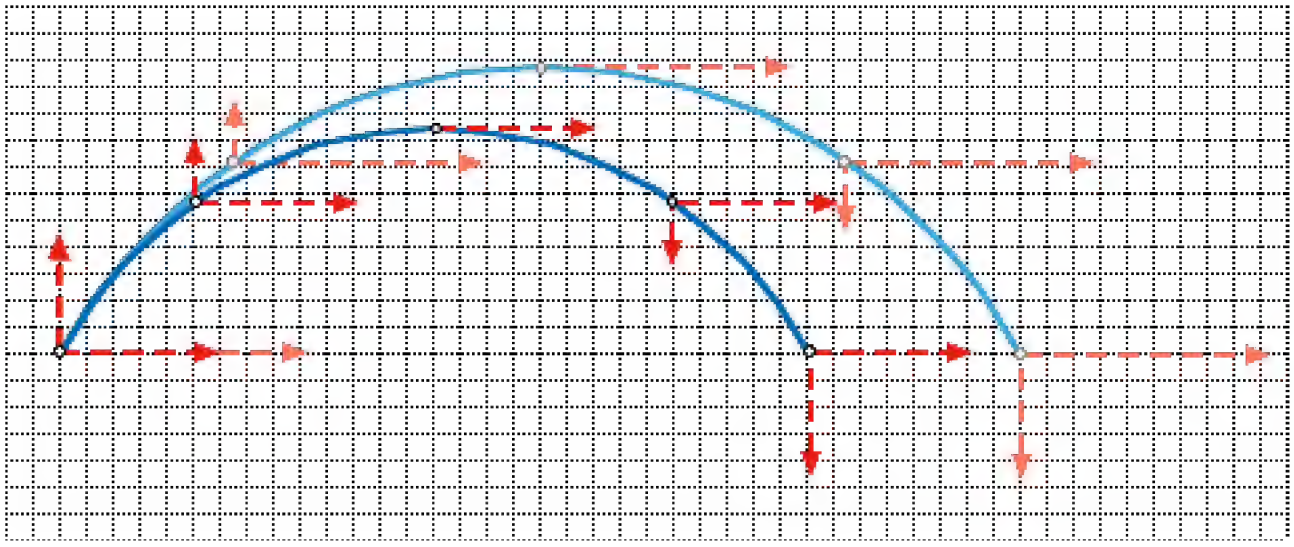
For most sports, the intention is to achieve the greatest possible horizontal distance. For a projectile where air resistance is ignored, the ideal angle of release is 45°, as this gives the greatest horizontal distance. For most implements thrown in athletics and other sports, the angle of release should be lower than this to allow for aerodynamic flight.

a Why is the ideal angle of release for a badminton shuttlecock much greater than 45°?

Because the effects of air resistance are quite pronounced

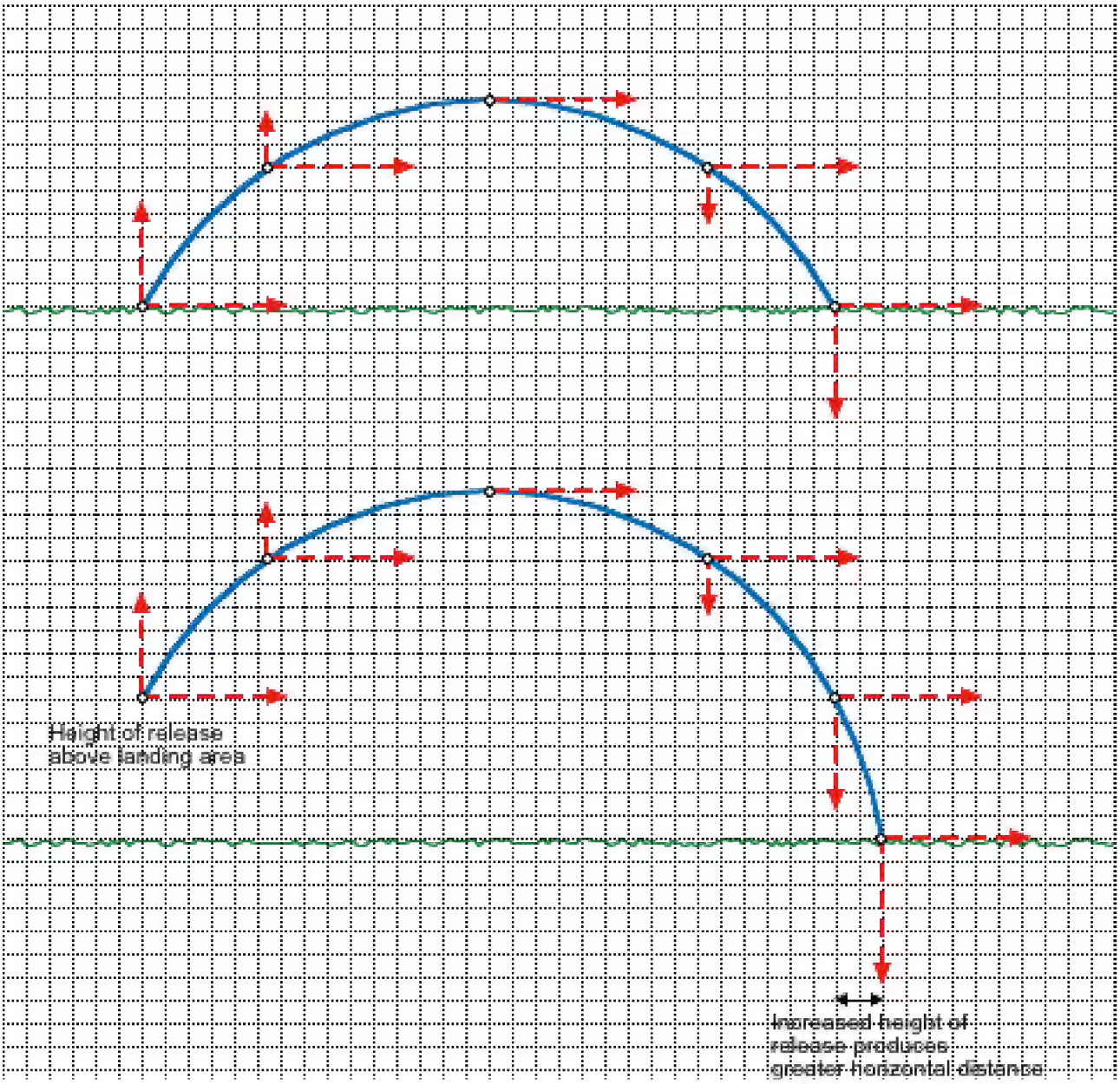
In simple terms, the higher the speed of release, the greater the horizontal distance achieved.

Thus:



Task 5 *continued*

The same principle applies to the height of release. The higher above the landing area that the projectile is released, the further it will travel.



Task 5 *continued*

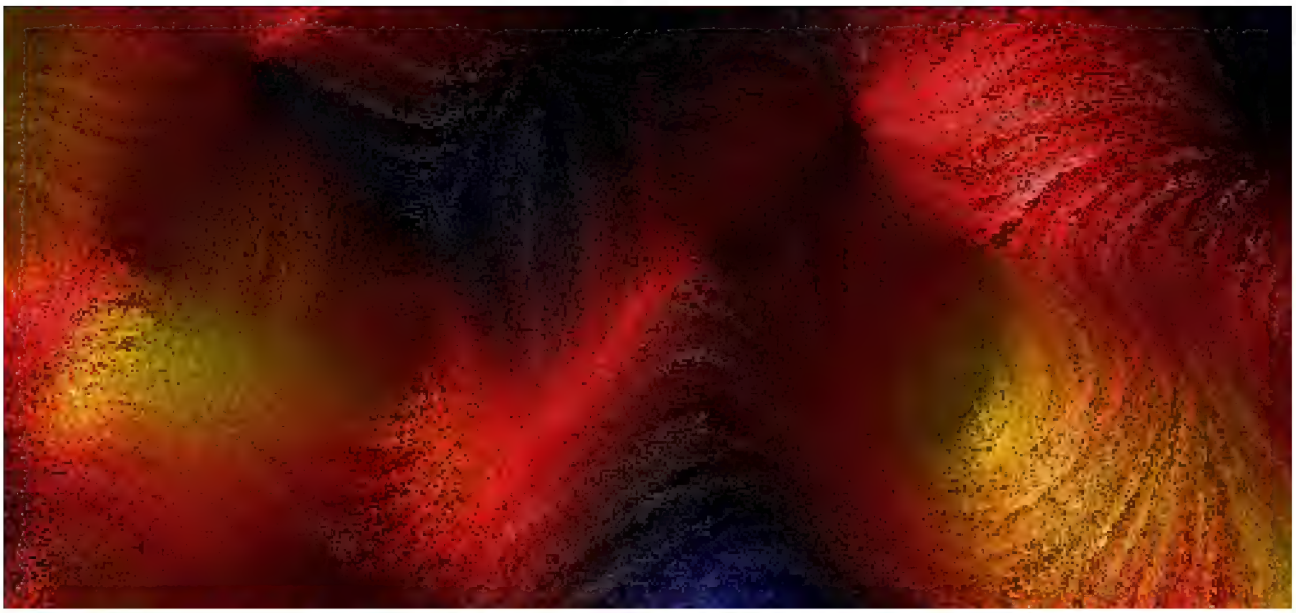
b Explain how each of the following factors, angle, speed and height of release affects the flight of a projectile.

Angle of release - close to 45 º to allow for maximum horizontal distance; Speed of release - the faster the speed of release the greater the horizontal and vertical components and hence the greater the horizontal distance achieved; Height of release - the greater the height of release, the longer the projectile is in the air and the greater the effect of the horizontal component will be.

Teaching Resource

Part 1 Mechanics

D Angular Motion



Feltham Press

General Considerations and Objectives

1. To allow students to understand and use appropriate terminology to describe angular motion
2. To enable students to appreciate the essential mechanical parameters that are apparent during performance

Tasks

In this study pack you will find a range of tasks that require the students to develop their knowledge of the terms and relationships involved in describing angular motion.

Students will need to

1. Understand the essential terminology used to describe angular motion
2. Appreciate the relationship between moment of inertia and angular velocity during flight and friction-reduced movement
3. Be able to apply these principles to observed performance

The concepts of angular motion are possibly easier to understand in terms of observed effects than those of linear motion, but harder to explain in terms of the mechanical principles that underpin them.

All the tasks involved require the students to work either from the tasks as free-standing units, or to use the tasks as additional reinforcement and/or revision to class-delivered lessons.

Assessment of this work could simply be as answers to the posed questions, or assessed as part of a group's work, or through class discussion.

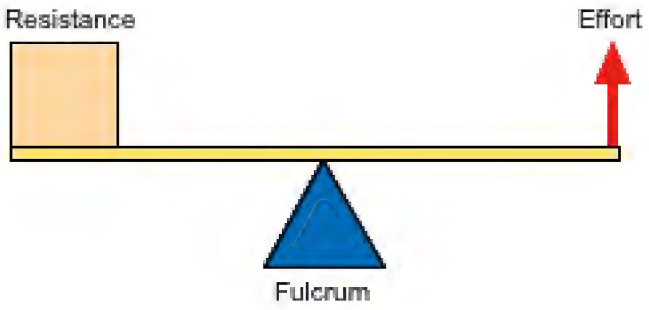
Task 1

Read the following materials, answering the questions in the spaces provided.

Angular motion occurs when bodies turn or rotate. When they do so, they rotate around an **axis** - think of a bicycle or car wheel rotating around the spindle/hub. In gymnastics, the performer on a high bar is rotating around the bar, which is the axis.

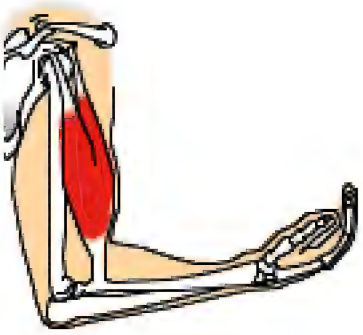
Human motion involves **rotation**. Even when we appear to be moving in a straight line – linear motion – the different parts of our body are actually performing angular motion. This is because all our movements involve joints, and our joints are lever systems that involve rotations around the joint (fulcrum).

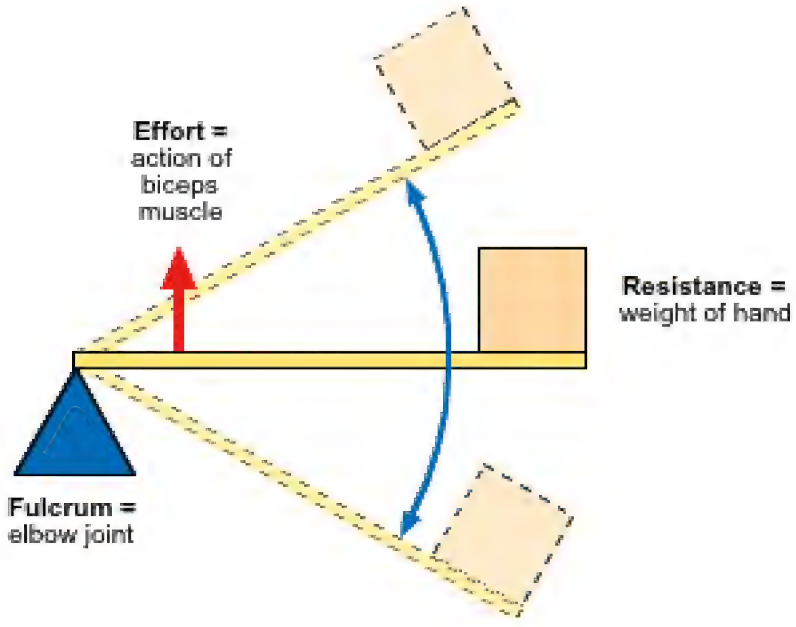
What class of lever system is shown in the following diagram? Label the various parts of the lever system.



First class lever system

When we perform a biceps curl for example, the biceps brachii muscle applies a force and the hand rotates around the axis formed by the elbow joint.





Task 2

Observe a video recording of an ice-skater spinning.

a Describe in your own words what happens to the performer's speed of rotation when he/she changes their body shape.

As the performers shape alters, so does their speed of rotation. The more compressed they are the faster they turn

When a body is rotating, the quantity or amount of rotation that it has is called its **angular momentum**.

Provided there are no external forces acting to interfere with its rotation, the angular momentum of a body will remain constant during its rotation.

In practice, during sports performance friction is a force that invariably causes changes in angular momentum. This means that the only time that there are no external forces acting on a body is when it is in the air, where the effects of friction (air resistance), are so small that they can be ignored.

In other words, the rotating, spinning or somersaulting gymnast, trampolinist or high board diver rotates with a constant angular momentum. Another situation where angular momentum is relatively constant is when ice-skaters spin on the ice.

Task 2 *continued*

b Why is it possible to consider angular momentum to be constant in this situation?

On ice, friction is so small as to be negligible

Angular momentum is made up of two components, the **angular velocity** and the **moment of inertia**, such that:

Angular momentum = angular velocity x moment of inertia

The angular velocity is the rate of spinning; the faster you spin the higher the angular velocity.

c If a gymnast is somersaulting would they need a high or lower angular velocity? Explain your answer.

The somersaulting gymnast would need a high angular velocity in order to complete their rotations as fast as possible, as their ability to remain airborne is strictly limited

The moment of inertia is concerned with the distribution of mass around the axis of rotation. The closer the mass is to the axis of rotation, the smaller the moment of inertia and conversely the more spread out the distribution of the mass around the axis of rotation, the greater the moment of inertia.

Task 2 *continued*

d If the same gymnast is performing a tucked somersault, is their moment of inertia higher or lower that if they were performing a piked somersault? Explain your answer.

During a tucked somersault, the gymnast's moment of inertia is lower than when performing a piked somersault, as their mass is more confined to their axis of rotation

Consider an ice-skater performing a spin. During the spin, the skater's angular momentum remains essentially constant.

e If they bring their arms in to their body, what do you observe about their rate of spin (angular velocity)?

They spin faster

f What has happened to the skater's moment of inertia by bringing their arms in to their body?

Their moment of inertia is reduced

In other words, because angular momentum remains constant; if we decrease the moment of inertia, we will correspondingly increase the angular velocity. Conversely, if we increase our moment of inertia, we decrease our angular velocity.

In practice, if we are rotating, to make ourselves turn faster (having a high angular velocity) we need to reduce the spread of our mass (moment of inertia) as much as possible.

This is why it is easier to perform tucked somersaults than piked somersaults, and why skaters spin faster with their arms close to their body.

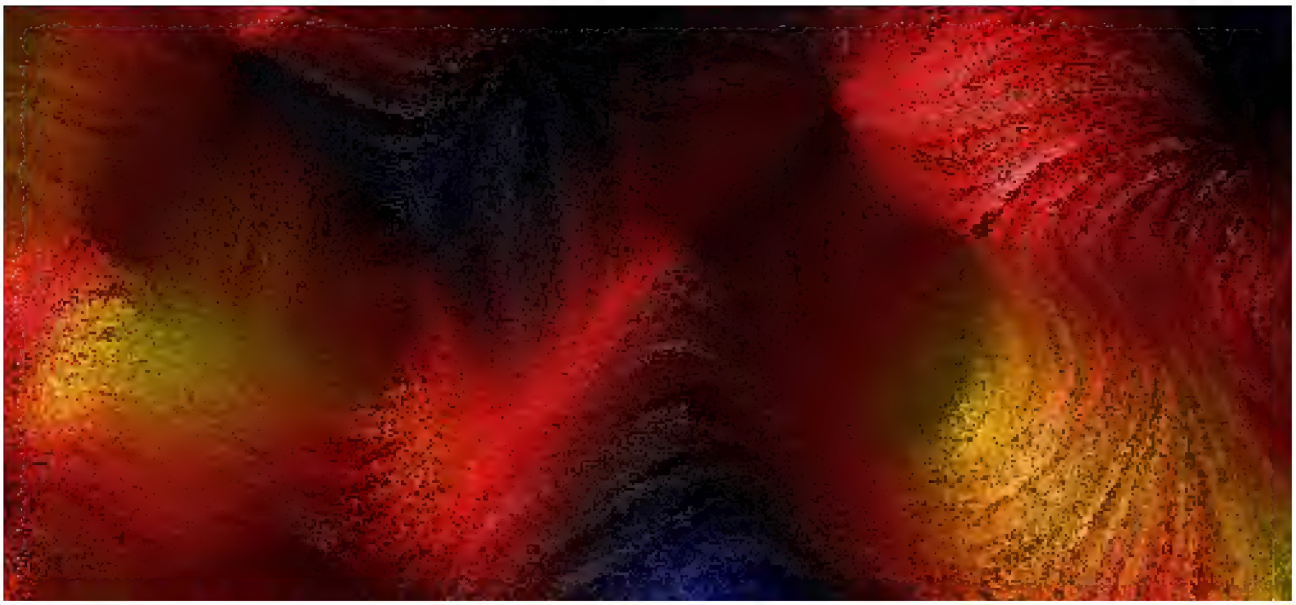
g Downhill skiers tuck up to reduce drag as they ski straight downhill, so that they increase their velocity and so complete their 'run' in less time. That being so, try to explain why slalom skiers tend to stand up as they turn around gates.

Standing up reduces their moment of inertia around the longitudinal axis of the body, so allowing them to turn quicker at the gates

Teaching Resource

Part 2 Differences in Fitness Measures

A Training Effects



Feltham Press

Introduction

The material in this section may appear to be relatively straightforward for teachers to deliver and students to understand, but problems arise with the depth of knowledge required by the specification.

Investigations into the physiological measures that define elite performance from the norm will soon reveal the need to understand a considerable amount of physiological knowledge, which in some cases is outside the realms of the specification, and therefore care needs to be taken in deciding which parameters may or may not be suitable for discussion.

Introducing parameters as simple measures and then applying those concepts to the effects they have on performance appears to be the way that the specification suggests and is the way used here.

Special Note on Units and Nomenclature

The preferred (SI) units are:
decimetre cubed (dm^3) rather than litre (l),
centimetre cubed (cm^3) rather than millilitre (ml),
joules (J) rather than calories (c).

The preferred names for organic acids are:
lactate (just the one word), rather than lactic acid;
pyruvate (just the one word), rather than pyruvic acid.

General Considerations and Objectives

1. To enable students to investigate the effects of training on the body from an understanding of the general adaptation syndrome
2. To allow students an insight into elite training through an understanding of periodisation and propriceptive neuromuscular facilitation
3. To investigate the benefits and problems associated with altitude training

Tasks

In this study pack you will find a range of tasks that require the students to develop their knowledge of the terms and relationships involved in describing training techniques and their effects.

Students will need to

1. Understand the essential terminology used to describe training adaptations
2. Understand the benefits to the elite performer of periodisation and proprioceptive neuromuscular facilitation.
3. Appreciate the effects of training on the body especially that of altitude training.
4. Be able to apply these principles to observed performance

For simplicity, we need to distinguish training and exercise. Training being the long-term, regular undertaking of a planned fitness programme whereas exercise is a single session of fitness activities.

All the tasks involved require the students to work either from the tasks as free-standing units, or to used the tasks as additional reinforcement and/or revision to class-delivered lessons.

Assessment of this work could simply be as answers to the posed questions, or assessed as part of a group's work, or through class discussion.

.

Task 1

Using textbooks and/or the internet as a resource, suggest a reason why the response occurs for each of the following parameters (measures) that are affected by undertaking exercise. Additionally for each parameter, find the normal range of values found in humans.

If textbooks fail to provide the information on normal values, then undertake exhaustive exercise and measure them!

The short-term effects of exercise include:

a Increased heart rate

Reason *to cope with the need to supply nutrients, especially oxygen to the working muscles*

Range *heart rate increases from its resting levels of 60 - 80 beats per minute, up to, depending on the intensity of the exercise, 150 - 200 beats per minute*

b Increased breathing rate

Reason *breathing rate increases in response to exercise, and the need to oxygenate the blood*

Range *from a resting level of about 12 - 15 breaths per minute, to levels approaching 30 breaths per minute*

Task 1 *continued*

c Increased depth of breathing

Reason *Depth of breathing increases to permit an increased oxygenation of the blood and to remove excess carbon dioxide*

Range *tidal volume increases from its resting levels of 500 cm^3 to levels that approach 1000 cm^3*

d Increased body temperature

Reason *the waste heat produced through energy production*

Range *From a normal 37° C to an exercising level closer to 40° C*

e Localised muscular fatigue

Reason *onset of exercise produces metabolic waste products (lactate) that may produce localised fatigue if they accumulate*

Range *resting levels of 1-3 millimoles of lactate per litre of blood may be considered normal, but during intense exercise this level may rise to 12 -16 millimoles, depending on levels of fitness*

Task 2

Using textbooks and/or the internet as a resource, describe and explain each of the following responses to long-term endurance training.

a Cardiac hypertrophy

Training increases the size of the heart. In endurance-trained athletes, this increase is due to an increase in the size of the ventricles, particularly the left ventricle. In non-endurance trained athletes, the hypertrophy is due to an increase in the thickness of the muscle of the ventricular wall

b Increased resting stroke volume

The larger chambers of endurance athletes will increase the amount of blood pumped out by the resting heart, the stroke volume, because the bigger chamber will allow more blood to enter the chamber whilst it is filling (increased extensibility), and a corresponding increased amount leave when the heart contracts. The thicker muscle of the non-endurance trained athlete will produce stronger contractions of the ventricles (increased contractility), and therefore eject a larger proportion (ejection fraction) of the blood that is in the ventricle, which results in a similar increased stroke volume

Task 2 *continued*

c Decreased resting heart rate (**bradycardia**)

As the demand for blood whilst at rest remains constant, so does the cardiac output. However, the increase in stroke volume described above, means that there will be a corresponding decrease in resting heart rate, because cardiac output = stroke volume x heart rate

d Increased blood volume and haemoglobin

Training causes an increased production of blood plasma and red blood cells, thus increasing the overall blood volume, and increasing the haemoglobin content, and hence the oxygen-carrying capacity of the body

e Reduced exercising and maximal heart rate

Because of the increased stroke volume of the heart, and as the cardiac output remains fairly constant, the heart rate during sub-maximal exercise decreases. Also, because of the increased stroke volume, it is often difficult for highly trained endurance athletes to increase their heart rates above 180 beats per minute

Task 2 *continued*

f Blood flow to working muscles decreases

Because muscles are better able to extract oxygen from the circulating blood, mainly because of increased capilliarisation within muscles (more capillaries form), thus increasing the capillary density

g $\dot{V}O_2$ max increases

As a result of increased maximal cardiac output and the improved oxygen extraction by working muscles

h Increased stores of glycogen and triglycerides

both are available for aerobic energy production

i Increased myoglobin content of muscle

Myoglobin takes up oxygen from haemoglobin, and thus provides a store of oxygen within muscle that is available when exercise commences

Task 2 *continued*

j Increased capilliarisation of muscle

Leading to greater efficiency of oxygen delivery

k Increased number and size of mitochondria

Leading to improved aerobic energy production

l Increased concentrations of oxidative enzymes

Leading to improved aerobic ATP production

Task 3

Using textbooks and/or the internet as a resource, explain each of the following responses to long-term strength training.

a Increased muscle stores of ATP and PC and the appropriate enzymes

Increases the muscle's capacity to generate anaerobic energy.

b Increased glycolytic capacity

Increases the muscle's capacity to generate anaerobic energy through glycolysis as a result of the increase in levels of stored glycogen and glycolytic enzymes

c Muscle hypertrophy

This is especially in fast-twitch fibres, as a result of which there are more contractile proteins (actin and myosin); an increased number and larger myofibrils; increased fibre size; increased cross-sectional area and therefore increased force

Task 3 *continued*

d Increased capillary density in each fibre

More capillaries means that more blood bringing oxygen and removing lactate can be transported to the muscle

e Increased ability to recruit more motor units

Hence produce more forceful contractions

Task 4

Read the following materials, answering the questions in the spaces provided.

Training at elite level is concerned with maximising performance for specific occasions. The training involved is based at two levels; improving fitness and improving technique. The basic idea to improve fitness is to identify the major energy system involved and use the overload principle to develop that particular energy system more than any other system.

a What do you understand by the 'overload principle'

Overload principle is the idea that you do more than normal in order to stress the body so that it will adapt to the stresses. The three factors to be considered for overload are the frequency, duration and intensity of training

To improve our ability to perform a certain task involves working **specific** muscles or organ systems at an **increased** resistance.

b What do you understand by the term specificity of training?

This means designing and implementing a training programme to develop specifically those energy systems and movement sequences involved in the chosen sports activity

Task 4 *continued*

c What do you understand by the use of the term increased resistance?

This refers to the overload principle which means stimulating the muscles and organ systems involved at an increasing level as fitness improves

Specificity and overload can result in faster movement, a more forceful movement or an improved ability to resist fatigue (improved endurance) – all of which lead to improved performance.

The primary energy system for any activity can be estimated on the basis of its performance time. The shorter the duration of an activity the more likely that it will involve anaerobic energy systems.

d Explain how a game activity may involve all three types of energy system.

Long duration hence aerobic systems used for walking, jogging and recovery; periods of sustained high energy output such as running 50 metres or running after a ball will involve the lactate anaerobic system; short duration periods of intense effort will involve the ATP-PC system, for example jumping, tackling, sprinting

Task 4 *continued*

The following table shows the percentage contributions of differing energy systems to various activities.

Note that there has yet to be discovered a means of determining an exact percentage contribution of any one energy system during an activity, and so the energy systems tend to be grouped as ATP-PC and lactate anaerobic; lactate anaerobic and aerobic; and aerobic only.

Sport	%ATP-PC and lactate anaerobic	%Lactate anaerobic and aerobic	%aerobic
Basketball	60	20	20
Football	60	20	20
Gymnastics	80	15	5
Rowing	20	30	50
Diving	98	2	0
Tennis	70	20	10
Athletics 100 m	95	5	negligible
Athletics 1500 m	20	25	55
Athletics marathon	negligible	5	95

e Suggest how coaches could use the information in the table to decide training programmes for their performers.

Coaches could (should!) use such tables to divide up the available time for training between stressing the different energy systems. Thus a tennis player should spend 80% of their time stressing their ATP-PC and lactate anaerobic systems, and 20% of their time working on their aerobic systems. Note that specificity could link in with movement sequences being stressed at the same time – in other words playing repeated shots would stress both the skill movements and the energy systems involved

Task 4 *continued*

Also note that the table presents proportional contributions during the whole performance. Thus a football striker may use the ATP-PC and lactate anaerobic system when sprinting for the ball and this type of activity represents 60% of his/her total energy demand. But this does not mean that the striker should spend 60% of their time stressing the ATP-PC and lactate anaerobic system. In soccer long periods of inactivity are interspersed with periods of high activity, and this is how training should be viewed.

Thus the energy sources for any activity are really both **time-dependent** and **intensity-dependent**.

It is also important to realise that the energy systems do not work in isolation. There is no 'switching' from one system to another

For any activity, differing levels of involvement will be occuring for each system.

Therefore it is more accurate to talk of the prediminant energy system. Thus during a 400 metre run, the predominant energy system will be the lactate anaerobic system, but the aerobic and PC systems will also be being used by some muscle fibres.

Task 5

Read the following materials, answering the questions in the spaces provided.

To overload we alter frequency, intensity and duration of training.

a Which one is the most important component for anaerobic training?

intensity

The intensity of anaerobic training may be determined by three methods: heart rate; blood lactate level and training pace/intensity.

b What is blood lactate?

Lactate (lactic acid) in the blood having been produced by anaerobic glycolysis (usually in muscles)

c Why should blood lactate levels indicate training intensity?

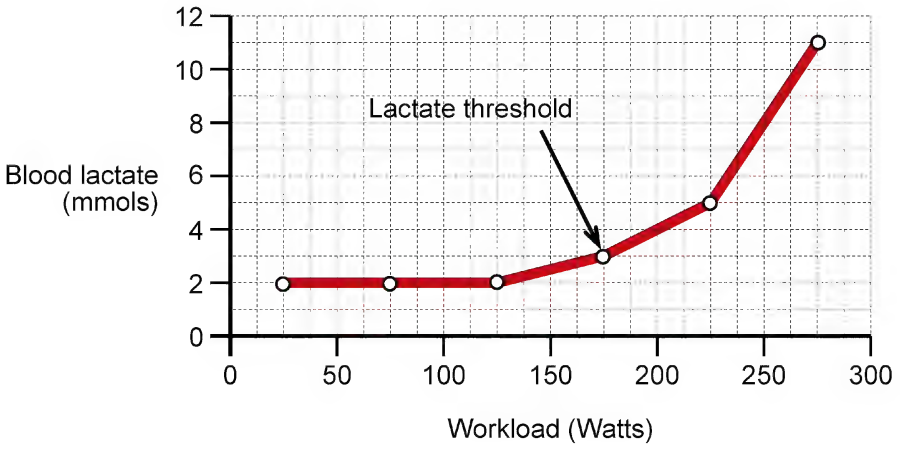
Higher intensity would produce more lactate

Task 5 *continued*

The **lactate threshold** of athletes is usually approximately 2-4 mmols of lactate per litre of blood, but this is about as accurate as saying that the average height of athletes is 1.8 m (5ft 10ins). In reality, lactate threshold needs to be determined for each individual athlete to avoid training them too hard or too easy.

Blood lactate is measured by sampling blood and measuring lactate levels at rest and then repeating the sampling and measuring procedure as the athlete undertakes exercise increasing intensity. Lactate threshold is defined as a level of lactate that is 1 millimole above resting levels.

d Add a label line to indicate the lactate threshold on the following graph



Once established, the heart rate and/or training pace at the lactate threshold may then be used to establish intensity.

In simple terms, the more frequently and the longer you train, the greater the improvement in performance. However, recovery from exercise is also very important, and recovery is assisted by aerobic energy systems, so there needs to be a limit to the amount of anaerobic training that is attempted.

Suggestions are that for the highly anaerobic specific activities (throws, sprints), training frequency might be 5-6 times per week, whereas for those activities with large aerobic component 3-4 times a week should suffice.

Duration is of greater variation, because the simple idea of continuous repetition of strenuous activity is both mentally and physically exhausting.

Task 5 *continued*

General guidelines for estimating intensity, frequency and duration of an anaerobic training programme are given below:

Training factor	Guideline
Intensity	Heart rate that is 5-15% above heart rate at lactate threshold
Frequency	3-4 days per week
Sessions per day	1 (possibly 2)
Duration	8-10 weeks
Duration per session	
ATP-PC system	Repeated work bouts of 25 secs or less
Lactate anaerobic	Repeated work bouts of 3-4 mins or less

e Use the information in the table and your own knowledge to describe a training programme for a throw athlete.

They should train once a day (occasionally twice); 3-4 times per week; at an intensity such that their heart rate increases to 10% above their lactate threshold level. Training should include work lasting 25 seconds of high intensity and 3-4 minutes of lower intensity work. There should be skill specific work – throwing action; as well as energy specific work – ATP-PC and lactate anaerobic. The training cycle should last at least 8-10 weeks

Task 6

Read the following information, answering the questions in the spaces provided

Training must be designed to improve the specific physiological capacities required for skilled performance. For aerobic performance this primarily involves the skeletal muscles, the cardio-respiratory system and/or neuromuscular function.

In terms of the skeletal muscles, there is a need to decide on the contribution of the energy systems used. Most endurance activities rely on the aerobic energy systems, however there are many activities such as the 400 metre swim, the 1500 metre run or playing midfield in soccer that require important contributions from anaerobic glycolysis as well.

The cardio-respiratory system is responsible for the delivery and exchange of oxygen and carbon dioxide between the air and the working muscles. Because of the need to transport sufficient oxygen to permit aerobic metabolism to continue, the cardio-respiratory system is more important during low-intensity, long-duration activities rather than very high-intensity short-duration activities.

The neuromuscular basis for aerobic training is the concept of the different type of muscle fibre found within muscles, and the fact that slow-twitch and FOG fibres are predominantly recruited for aerobic-type activities.

Overload is again used to improve fitness for aerobic activities, where the principal aim for elite athletes is to improve performance or increase $\dot{V}O_2$ max.

a What do you understand by the term $\dot{V}O_2$ max?

$\dot{V}O_2$ max is the maximum amount of oxygen

that can be used by the body per minute

Task 6 *continued*

There is a general misconception that athletes train at an exercise intensity that is equivalent to their $\dot{V}O_2$ max. This is not the case. More realistically, training intensity takes place at some percentage of $\dot{V}O_2$ max, and this intensity level is usually just above the lactate threshold.

b What is the relationship between $\dot{V}O_2$ max and lactate threshold?

Lactate threshold is some proportion (percentage) of $\dot{V}O_2$ max. As fitness improves, so does $\dot{V}O_2$ max and lactate threshold, with the greatest improvements being made in lactate threshold, such that in elite athletes, lactate threshold may reach 90% of $\dot{V}O_2$ max

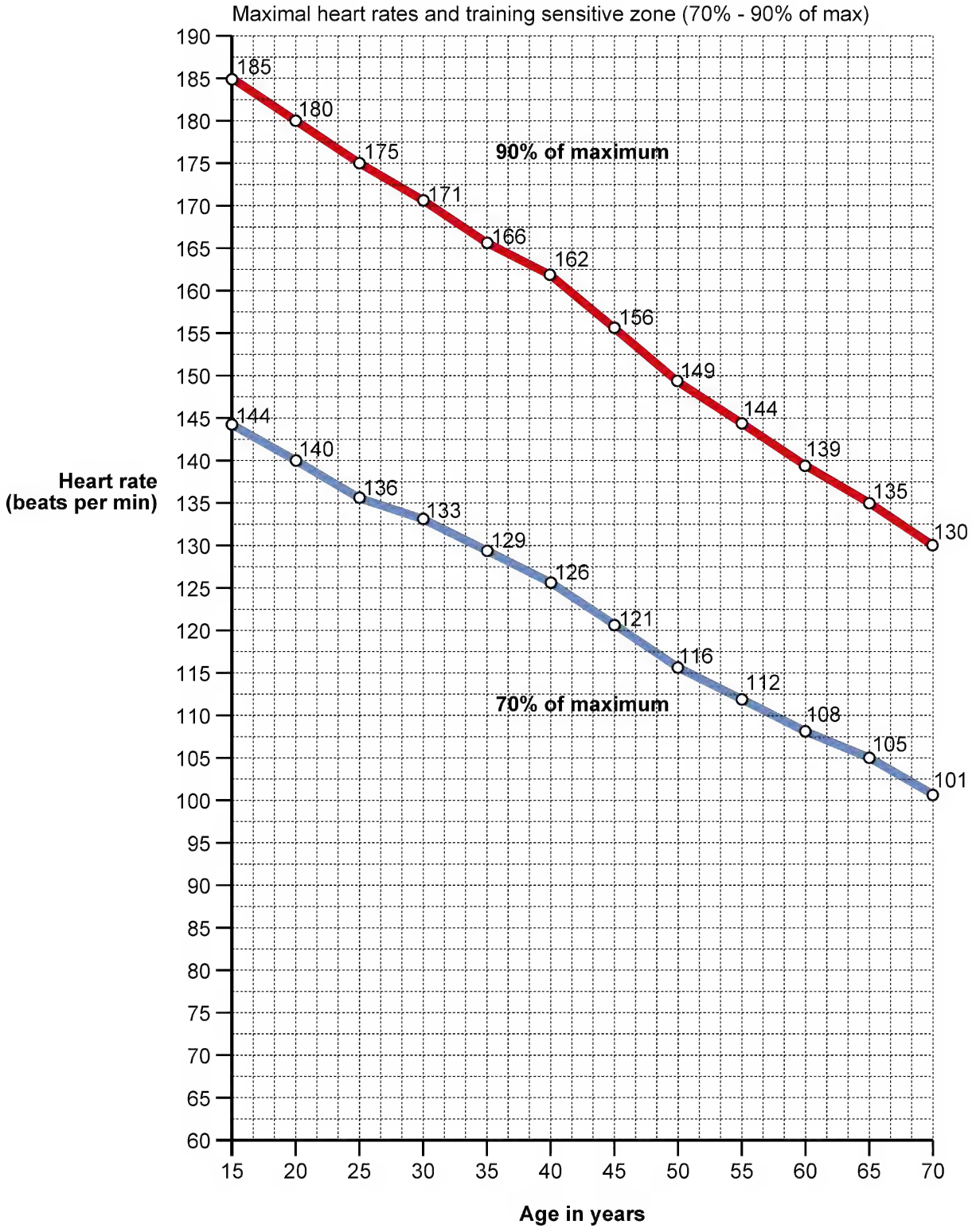
During training, the general aim would be to increase intensity so that exercising $\dot{V}O_2$ is somewhere between 70 and 80% of maximum, although in the case of elite athletes, these values may be nearer 85 or even 90%.

It seems therefore sensible to suggest that $\dot{V}O_2$ needs to be measured during each training session. But as such measures are relatively complicated, easier indirect methods are used as an alternative. These methods use either heart rate or lactate threshold.

A simple heart rate method relies on the fact that there is a linear relationship between heart rate and $\dot{V}O_2$. This method assumes that for aerobic benefits, exercise should result in the heart reaching a percentage of its maximum, called the target heart rate. Maximum heart rate is estimated at 220 minus age. A level of intensity above 70% of maximum heart rate will be required as fitness improves - progressive overload.

Task 6 *continued*

The graph below shows the training sensitive zone that represents the lower threshold for aerobic gains (70% of max heart rate), together with the upper level of 90% max heart rate.



Task 6 *continued*

c Explain how the graph shown above may be used to measure intensity of training and also improvements in fitness.

As intensity of exercise increases so does heart rate because there is a linear relationship between heart rate and $\dot{V}O_2$ max. This relationship is age-dependent because maximum heart rate reduces with age. Exercising at a known heart rate may be used as a measure of exercise intensity. Any improvements in fitness will result in corresponding improvements in the percentage of maximum heart rate achieved during maximum exercise, or conversely, improvements in fitness will be noted through the reduction in exercising heart rate achieved during a performance of standard intensity

A more accurate method involves using a heart rate monitor to measure the exercising heart rate, and apply the **Karvonen principle**. This method requires an initial calculation of the **heart rate reserve**, which is simply the difference between resting heart rate and maximum heart rate. For example if your resting heart rate is 65 and your age-determined maximum heart rate is 200, your heart rate reserve is 200 – 65 = 135.

The target heart rate is then calculated as a percentage of the heart rate reserve added to the resting heart rate. Thus calculating the target heart rate for a 20-year-old with a resting heart rate of 70 beats per minute who is wishing to exercise at 60% of their heart rate reserve:

aerobic training intensity =
[(max heart rate - resting heart rate) x 0.6] + resting heart rate

Max heart rate = 220 - age
for a 20 year-old male
= 200 and resting heart rate is 70,

thus aerobic training level = $\frac{[(200 - 70) \times 60]}{100} + 70 = 148$

It is therefore recommended that for improving endurance, this person should exercise at a heart rate of 148 beats per minute.

Task 6 *continued*

d Explain in your own words the use of the Karvonen principle for estimating exercise intensity.

The Karvonen principle involves using the resting and maximum heart rates to calculate the heart rate reserve, and then exercising at some percentage of that reserve to maintain intensity

e Calculate the heart rate required for a 30 year old with a resting heart rate of 50 beats per minute who needs to exercise at 70% of their heart rate reserve.

max heart rate = 220 – age
= 220 – 30
= 190
Heart Rate Reserve = 190 – resting HR
= 190 – 50
= 140
Exercising heart rate is
70% of heart rate reserve + resting HR
= (70% of 140) + 60
= 98 + 60
= 158 beats per minute

Positive adaptations in cardiovascular fitness and aerobic capacity can occur quite rapidly. Generally, exercising at least three days a week is required to bring about adaptive responses to the aerobic system, and it has been found that the training needs to be continued for at least six weeks to achieve any major benefits. Extra training does not produce that much extra benefit. Again in general terms (remember specificity!), performing continuous, moderately-paced exercise for 20-30 minutes per session is a realistic recommendation for exercising in terms of intensity of effort and time commitment, to produce aerobic improvements in the normally sedentary individual.

Task 7

Read through the following information, answering the questions in the spaces provided.

If you want to improve your performances, you can't train the same way all the time. If you did, your body would simply adapt to the training you were doing, your fitness would settle in at a fixed level, and you could train far into the next century without making one inch of improvement. Hoping to perform better with an unchanging training programme is like expecting to become a maths wizard while working on only the simple equations encountered in first-year algebra.

Complicated definitions for periodisation exist, but the term simply means the division of your overall training programme into periods which accomplish different goals. Since you can't do everything at once, you must divide your training time up into discrete blocks and tackle one or two goals at a time.

a What do you understand by the term periodisation?

Periodisation is the name given to the idea of dividing a training programme up into blocks or units of work

Task 7 *continued*

Periodisation is a method of elite training involving blocks of time devoted to certain tasks. These time blocks range from single training sessions to many sessions spread out over several months to even a year of training. These blocks of time are called **macrocycles**, which can be further subdivided into shorter time blocks called **mesocycles**, and even shorter **microcycles**. Macrocycles are the blocks of time that lead up to an elite performer's major competition – the championships.

According to convention, a 'microcycle' is simply a number of training sessions that form a recurrent unit. For example, if your training consists of a hard day, an easy day, and then a rest day, followed by the hard-easy-rest pattern again, these three days represent your basic training unit, or microcycle. Or, if you're a runner and your typical training week consists of a hill workout, an interval session on the track, a long run, three easy runs, and a rest day, that repetitive weekly pattern is your microcycle. The rugby player who trains in the gym on Monday, on the pitch on Wednesday and plays on Saturday is taking part in a weekly microcycle

In contrast, a 'mesocycle' is a block of training, consisting of some number of microcycles, which emphasises the attainment of a particular goal. This could be the pre-season (winter) training of the athlete to develop the necessary strength to improve their hammer-throwing performance. Similarly the repeated practice to improve the rugby player's line-out throwing that takes place over several weeks of training is a mesocycle.

A 'macrocycle' is a long stretch of training that is intended to accomplish an extremely important overall goal, such as the preparation for and completion of a very important marathon, or the achievement of a medal at a major championship, or the year long preparation for a Cup Final performance. A macrocycle is made up of a number of different microcycles and covers a period of many months.

Task 7 *continued*

b Distinguish between macro-, meso- and microcycles, giving an indication of how long each cycles lasts.

A macrocycle is a block of training that is intended to reach an ultimate goal; a mesocycle is a shorter component of that training block and a microcycle is a short period of a mesocycle. Typically, a microcycle lasts for five to 10 days (for many athletes, a microcycle is simply one week of training in a predictable way), a mesocycle usually covers four to 12 weeks, and a macrocycle lasts for 10 to 12 months.

Many athletes who periodise their training don't alter their macrocycles very much; one year is structured very much like the next, and thus the year is the largest unit of periodisation. However, some athletes think longer term and may utilise what are called 'large macrocycles' which consist of two to four 'small macrocycles,' each of which lasts about a year. These small macrocycles may differ from each other considerably.

For example, a high jumper preparing for the Olympics in the year 2004 might spend most of the year of 2002 (the first small macrocycle) working on agility, flexibility, strength, and power, devoting little time to actual jumping or competition, and then shift over in 2003 (the second small macrocycle) to a much greater emphasis on technique and an increase in the number of competitive efforts. In this case, the 32-month period from the beginning of 2002 to the summer Olympic Games in 2004 could be considered the large macrocycle.

Task 8

Read through the following information answering the questions in the spaces provided.

In simple terms, training at altitude should improve endurance performance. The speculative reason for this is the obvious success of the Kenyan and Ethiopian athletes in long and middle distance races. The more scientific argument is the idea that altitude training will increase the numbers of red blood cells and hence oxygen transport.

Normal training at sea level causes **oxygen stress**, where the level of exercise intensity makes the delivery of oxygen to the muscles for energy production difficult. As a result of this stress, the body produces more red blood cells, containing extra haemoglobin for the transport of oxygen. This increase in red blood cells is due to the action of **erythropoietin** (EPO)

At altitude there is far less oxygen in a sample of air, and this situation also causes oxygen stress and similar body responses of more red blood cells. Hence living at altitude produces the same beneficial effects in terms of increased oxygen transport capacity as endurance training.

a Suggest why altitude training might improve performance.

High altitude, less oxygen, adaptations over time to produce more red blood cells, giving improved oxygen transport and endurance performance on return to sea level

Task 8 *continued*

b What affect would you expect altitude training to have on anaerobic performance?

Explain your answer.

We should expect no difference in anaerobic performance because anaerobic performance does not depend on oxygen transport. However there may be some improvements because of the rarefied air giving less air resistance (friction) in activities involving speed (sprinting and throwing).

The idea would thus be to live and train at altitude to improve endurance performance, and many elite performers do this. However the effects of altitude training are not as clear-cut as first imagined.

Although living at altitude improves the numbers of red blood cells in the body, training at altitude is not that beneficial. The lack of oxygen in the atmosphere seriously limits the performer's ability to train at maximum intensity.

c Suggest why this might be the case.

Lack of oxygen at altitude means a reduced $\dot{V}O_2$ max, which in turn means that training cannot be as intense as at sea level, and therefore fitness declines.

Hence, although numbers of red blood cells increase, aerobic fitness actually decreases!

The solution could well be to live at altitude and train at sea level! This method is now being used for some elite athletes. They live high up in Mountains (altitude) and go back down to sea level to train (cable cars) each day. In the US and Scandinavia, there are athletes who spend most of their days in specially designed houses where the atmosphere is artificially maintained as if it was at altitude, and they can then train outside at sea level.

Task 9

Read through the following information, answering the questions that are set in the spaces provided.

There has been considerable debate about which type of stretching is best for improving flexibility, but recent evidence suggests that proprioceptive neuromuscular facilitation (PNF), or 'contract-relax' stretching, may be the most effective technique. If a muscle is stretched for about 6 seconds, the stretch reflex becomes inhibited.

a Explain the stretch reflex.

The stretch reflex occurs when a muscle is suddenly overstretched. This sudden pull is detected by stretch receptors in the muscle and a nerve impulse is relayed to the muscle concerned such that it immediately contracts to try and prevent the damage that might occur through over-stretching. Most common example of this is the knee-jerk reflex.

Task 9 *continued*

b Research through the internet, or through textbooks and write an account of the PNF method of stretching

For example, if you want to use PNF on your calf muscles, simply stretch your calves passively for a while, then contract your ankle flexors (the 'shin' muscles in the front part of your lower leg) and then stretch your calf muscles again. Or you can stretch your calves, CONTRACT your calf muscles vigorously (doing so initiates a reflex which helps the calves loosen), relax your calves and tighten your shins, and then stretch out your calf muscles again. Regular stretching using PNF can improve your flexibility by 10-15 per cent in just four to six weeks.

Passive stretching (often with the assistance of a partner) of a limb to the limits of its range of movement is followed by an isometric contraction of the muscles involved for about 6 seconds. The muscles are then relaxed, and the range of movement can now be increased as a result of the proprioceptors helping (facilitating) stretching by means of neuromuscular events.

c How does PNF improve stretching?

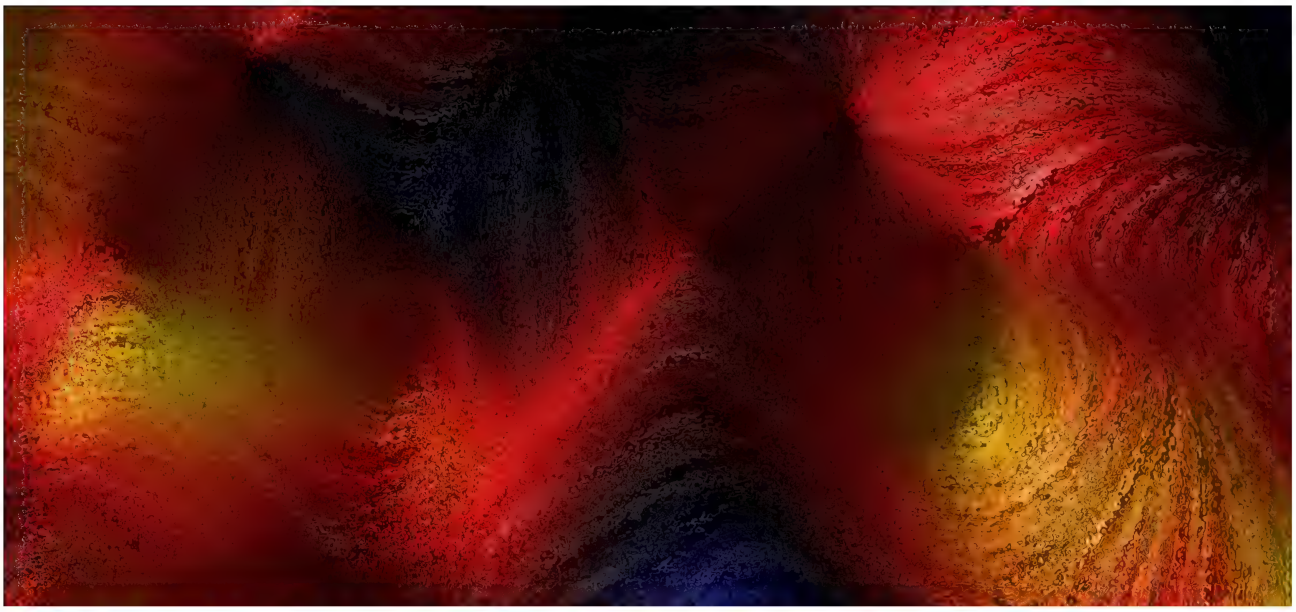
PNF inhibits the stretch reflex, allowing joints to be moved through a greater range of movement than is normally permitted

Fortunately for most athletes, PNF is easier to do than explain how to do.

Teaching Resource

Part 2 Differences in Fitness Measures

B Differences in Fitness Measures between Groups



Feltham Press

General Considerations and Objectives

1. To enable students to investigate the differences in fitness measures between elite male and female performers and the general population
2. To investigate the physiological causes of the male/female differences

Tasks

In this study pack you will find a range of tasks that require delete students to develop their knowledge of the terms and relationships involved in describing fitness parameters and their range.

Students will need to

1. Understand the essential terminology used to describe fitness parameters
2. Understand the causes of the differences between fitness measures of the elite performer and the general population as well as the male and female performer
3. Be able to apply these principles to observed performance

Experience suggests that students have little idea of elite performance. Their view of elite performance is often limited to TV. Simple schemes such as measuring out world jumping and throwing records, may bring elite performance into their perspective. Attendance at elite performance events is also worthwhile, especially if areas such as warm up areas can be entered for close-up views.

All the tasks involved require the students to work either from the tasks as free-standing units, or to use the tasks as additional reinforcement and/or revision to class-delivered lessons.

Assessment of this work could simply be as answers to the posed questions, or assessed as part of a group's work, or through class discussion.

.

Task 1

The table shows the range of values for various physiological parameters that are found between average and elite performers.

Parameter	Average Performer	Elite performer
Resting heart rate (beats.min^{-1})	60-80	40-60
Maximum Heart rate (beats.min^{-1})	180-190	170-180
Maximum Blood Lactate level (mmol.dm^3)	6-8	10-14
$\dot{V}O_2$ max (dm^3.min^{-1})	3-4	5-6

a Explain the causes of the decreased resting heart rate found in elite performers.

Training increases the stroke volume, but cardiac output remains essentially constant, hence resting heart rate decreases.

b What are the benefits of a reduced resting heart rate to an elite performer?

Greater heart rate range; less oxidative output to cardiac muscle - more available to skeletal muscle.

Task 1 *continued*

c Suggest why the maximum heart rate of an elite performer is lower than that of an average person.

Large ventricles of elite performer take longer to fill - hence cannot beat as fast as untrained heart.

d What is the cause of the increase in blood lactate levels during exercise?

Lactate from (intense) anaerobic exercise; pyruvate converted to lactate rather than entering mitochondria; muscle lactate diffuses into blood.

e Define $\dot{V}O_2$ max.

Maximum volume of oxygen used per minute of exercise

f Why is $\dot{V}O_2$ max used as a measure of cardio-respiratory endurance?

Oxygen consumption related to energy production via aerobic metabolism - hence more oxygen used equates to more energy produced.

Task 2

Read through the following information, answering the questions in the spaces provided.

There are several physiological differences between males and females, some of which lead people to the conclusion that males are able to perform better in a sporting context.

The average female has a larger level of percentage body fat than the average male; 25% as compared to 12.5%.

a Why should the levels of fat in the body create a difference between male and female performance?

Fat represents non-productive weight and increases mass, which in turn reduces stamina

A higher fat level is an advantage to aquatic sports such as swimming, where fat is more buoyant than muscle, and also acts as an insulator against the cold. But in most sports, the body's weight has to be supported on the legs, and endurance is an important factor. Here the additional fat is a disadvantage. The extra mass increases the amount of work that has to be done to support and move the body. It effectively decreases the $\dot{V}O_2$ max.

b What are the units of $\dot{V}O_2$ max?

Either dm^3 per minute or cm^3 per kilogramme of body mass per minute

The extra fat of females forms a thicker layer just below the skin's surface, and this acts as an insulating layer, preventing heat loss. The idea however that the extra fat carried by the average female was of some advantage in endurance events because of their ability to use fats in such events has now largely been discredited.

Task 2 *continued*

The female skeleton is smaller, lighter and has shorter limbs, and hence levers, than the male.

c How might these differences in limb length affect performance?

Shorter levers are easier (quicker) to move, but correspondingly generate less velocity, hence female limbs are unable to apply as much force as males in throwing events.

These differences are of some advantage to the female in those activities involving balance and agility, but they also produce disadvantages. The wider pelvis of the average female, for example, means that there is a greater angle between the femur and the pelvis, which reduces the efficiency of the running action.

The narrow shoulders also mean that the female's upper body is less muscular than the average male's, and therefore weaker in relation to the lower body than in males. The narrower shoulders of the female reduce the size of the chest cavity, and so the female has a smaller lung capacity.

Females in general have a smaller heart, and therefore a smaller stroke volume, smaller cardiac output, and a faster resting heart rate.

There is no difference between the maximum heart rates of males and females. The smaller cardiac output of females means that they can deliver less oxygen to their tissues, and therefore their levels of endurance are reduced as compared to males.

Females also have a reduced blood volume (6-8 dm^3) and haemoglobin concentration (13 g per 100 cm^3 of blood), as compared to males (8-10 dm^3 and 15 g per 100 cm^3 of blood respectively).

d What fitness parameter will this affect?

$\dot{V}O_2$ max will be reduced – there being less blood transporting less oxygen to exercising muscles

Task 2 *continued*

There is no difference in muscle composition between the sexes, but, there are lower levels of the hormone testosterone in females

This means that they do not develop as much muscle mass in response to training as do males, and they also lose strength gains quicker than males.

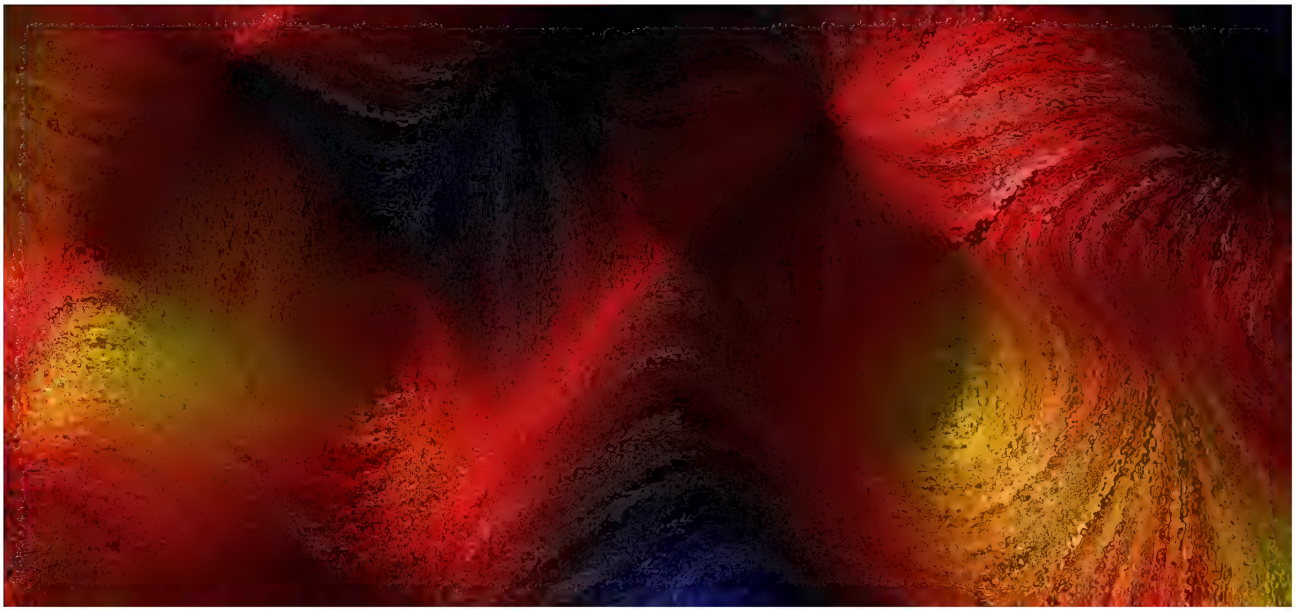
e Suggest why females tend not to be as strong as males.

Females have a smaller chest cavity and skeletal frame for the attachment of muscles, hence smaller muscles; also males have more testosterone and therefore are most able to increase muscle mass through training

Teaching Resource

Part 3 Energy Concepts

A Energy Sources



Feltham Press

Introduction

The biochemical requirements of this aspect of the course need to be reduced to make the processes involved understandable to the average non-scientific A-level student. Terms such as electron transport, hydrogen acceptor, and oxidative phosphorylation have little place at this level of study of energy systems.

The premise here is to make students aware that the different demands placed upon elite performers during different performances may be met by energy provision from different sources and through different metabolic processes.

Following the development of the main aspects of the energy systems should be a detailed look at how these systems operate under differing conditions, with the emphasis on the idea of a predominant energy system rather than switching on and off of any particular system.

Factual information may be presented in a variety of formats to aid reinforcement. Posters, PowerPoint, role play, video, etc are all valid and reliable alternatives to chalk and talk for a topic area that tends to confuse rather than simplify.

General Considerations and Objectives

1. To allow students to understand and use appropriate terminology to describe the main sources of energy and their location
2. To enable students to appreciate the interconversions possible within the body

Tasks

In this study pack you will find a range of tasks that require the student to develop their knowledge of the terms and inter-relationships involved in describing energy sources.

Students will need to

1. Understand the idea of the main foods used as energy sources and their location within the body
2. Appreciate the inter-relationship between the different sources of energy
3. Be able to apply these principles to observed performance

The idea of foodstuffs being utilised as energy sources is relatively simple to understand, any problems that arise are usually due to the nomenclature used, which may confuse non-scientists. In order to avoid this it is best to keep terminology to a minimum and avoid knowledge of alternative terms.

Students are asked to work through a series of fairly simple tasks. All the tasks involved require the students to work either from the tasks as free-standing units, or to use the tasks as additional reinforcement and/or revision to class-delivered lessons.

Assessment of this work could simply be as answers to the posed questions, or assessed as part of a group's work, or through class discussion.

Task 1

Read through the following materials, answering the questions in the spaces provided.

We obtain our energy from the food we eat, namely carbohydrates, fats and proteins.

a For each of carbohydrates, fats and proteins suggest 2 foods that contain a high proportion of these nutrients.

carbohydrates - bread/cakes/rice/pasta/potatoes.

fats - butter/cream/lard/oil.

proteins - meat/chicken/cheese.

Following digestion, these chemicals will become **glucose**, **fatty acids** and **glycerol**, and **amino acids** respectively. These substances enter the blood system and become available for the body. Glucose in the blood system may be used by working muscles as a source of energy. Excess glucose that enters the blood following a meal is stored in muscles and the liver as **glycogen**.

Task 1 *continued*

b What are the principle forms of carbohydrate found in the body, and how do these forms differ?

Glycogen and glucose; Glycogen is the insoluble storage form of carbohydrate found in liver and muscle; Glucose is the soluble blood-based form.

When our glycogen stores are full, then the excess glucose is converted to fat and stored in **adipose tissue**, which lies just under the skin. When required fats may be converted into glycerol and fatty acids. Glycerol and fatty acids (free fatty acids) may be used directly from the blood, but most are converted back into fats and stored as **triglycerides** in adipose tissue.

Glycerol may be converted into glucose, which is what happens when the diet is deficient in carbohydrate, or when glycogen stores have been depleted, as happens during a marathon.

c Explain in your own words how excess carbohydrate and fat are stored by the body.

Excess carbohydrate and fat are stored as fat droplets in cells within adipose tissue

Task 1 *continued*

Amino acids are usually used by the body for growth and repair, but unlike carbohydrates and fats, excess amino acids cannot be stored. Instead they are broken down by the liver (**deamination**), and the nitrogen-containing part of the molecule is excreted as urea. When we exercise, the remainder of the deaminated amino acid may be converted into glucose, or used in some stage of the energy production system. Up to 10% of our energy demands may be met through protein breakdown.

To a certain extent, the food sources are inter-convertible. This is predominantly a function of the liver. In practice, some conversions are easier than others. Thus the liver readily converts excess glucose into fat, but less readily into glycogen. The reverse reactions, converting glycogen into glucose are easily done in the liver, but less readily accomplished in muscles, whilst very little glucose can be produced from fat.

When we are resting, approximately a half to two thirds of our energy comes from fats, whilst the remainder comes from carbohydrate. This ratio alters when we exercise, but the exact proportions depend on many factors such as the type of exercise, the type of diet, the level of fitness and the type of muscle involved.

Muscles are able to use their stored glycogen as an immediate source of energy at the start of exercise and during intense exercise. During such times, the supply of oxygen to the muscles is limited and therefore complete aerobic breakdown is not possible.

d Why is the complete breakdown of glucose and fat to provide energy called an aerobic process?

Because it uses oxygen

Task 1 *continued*

There are certain advantages to the body in using carbohydrates as an energy source:

Only carbohydrates may be broken down without oxygen (**anaerobically**) by contracting muscles.

The **anaerobic** breakdown of carbohydrates by muscles produces **lactate** which increases the acidity (decreases the pH) of the fluids in the muscles, and this prevents free fatty acids from being used as an energy source.

Carbohydrates actually produce more energy for a given volume of oxygen than fats

e What are the advantages of using carbohydrates as an energy source?

Possible anaerobic metabolism; anaerobic useage inhibits fat metabolism (lactate); more energy per unit of oxygen used; energy released more rapidly.

Exercising muscles can obtain glucose from various sources.

f Give three sources of glucose for the muscles?

Stored glycogen; stored fat; blood glucose (use of protein is relatively small).

Task 1 *continued*

However, the brain is only able to use blood glucose for energy, and so levels of plasma glucose must be maintained, and this is what most liver glycogen is used for.

Using muscle glycogen as an energy source presents a problem as such stores are limited, and muscle fatigue rapidly occurs when glycogen stores are depleted. This is why the use of fat as an energy source is so important during exercise that lasts longer than 2 hours.

During recovery from exercise, there is an initial rapid replacement of used glycogen, but complete recovery, in terms of glycogen stores, may take more than 24 hours. Summarising, we may say that the more intense the exercise the more we use carbohydrate for energy, but the longer (more endurance-based) the exercise, the more we use fats.

Fat may only be used as an energy source if oxygen is present. Therefore the use of fat depends on the supply of oxygen to the muscles. In slow-twitch muscles especially, fat is the main energy source during exercise lasting more than an hour. Because training increases the capacity of the body to supply oxygen to the working muscles, it also increases the ability to use fats.

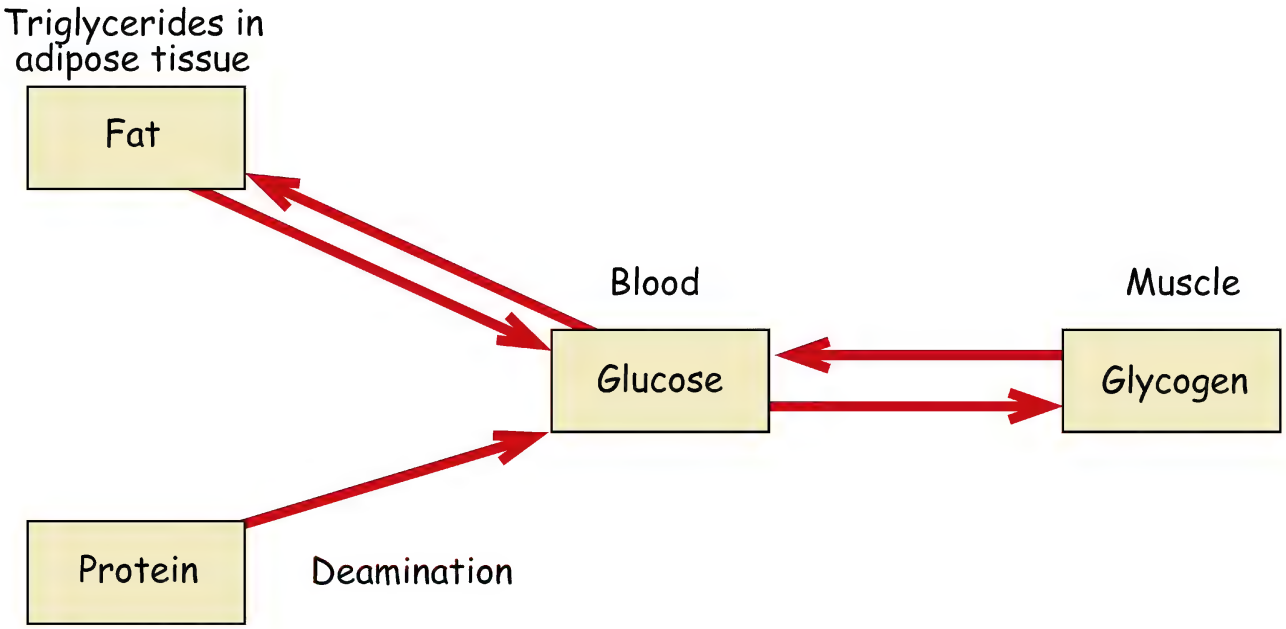
Very little fat is stored in muscles, and therefore the glycerol and fatty acids must be supplied by the blood. Glycerol released from fat stores may be used directly or be converted into glucose for use in the normal way. Adipose tissue releases free fatty acids, which are transported around the blood, bound to proteins.

g Summarise in your own words the usage of carbohydrate and fat during exercise of different intensities.

At low intensities fat can be the predominant energy system used (up to two thirds), but as intensity increases so does the proportion of carbohydrate used. Fat use is governed by oxygen availability. When oxygen becomes a limiting factor, fat metabolism must slow.

Task 2

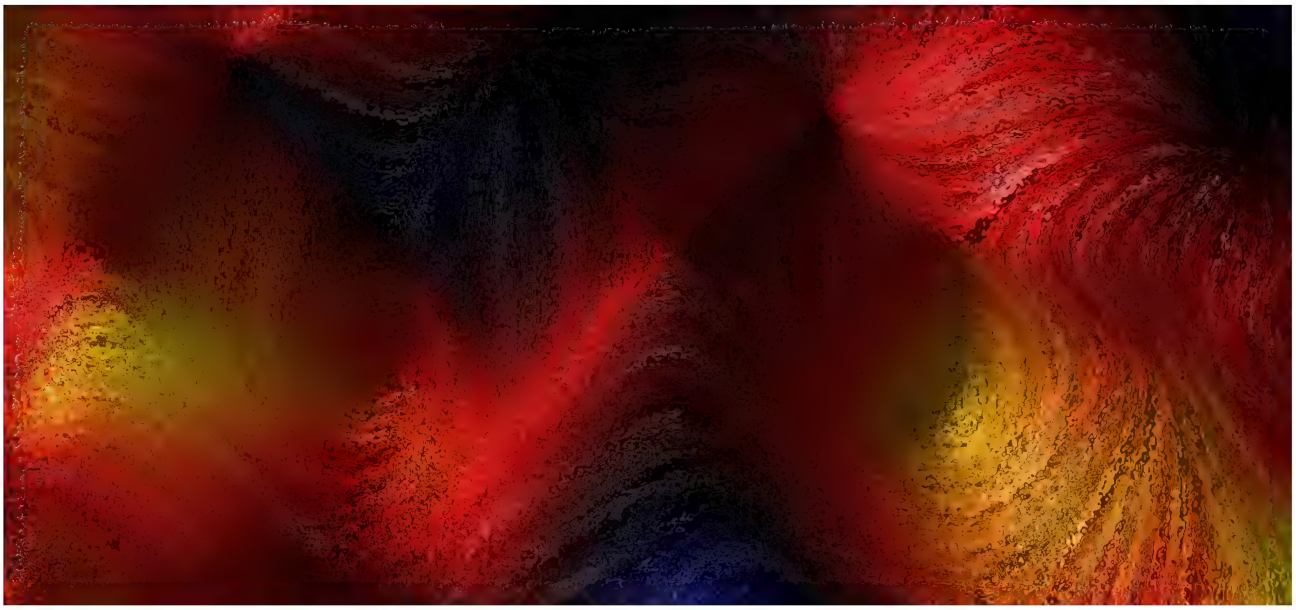
a Produce a flow chart, poster or a PowerPoint presentation that shows the interconversion of the different types of food within the body.



Teaching Resource

Part 3 Energy Concepts

B Muscle Fatigue



Feltham Press

General Considerations and Objectives

1. To allow students to understand and use appropriate terminology to describe possible causes of muscle fatigue
2. To enable students to appreciate the essential ideas behind the process of carbohydrate loading
3. To demonstrate the problems that exercise has on fluid retention and temperature regulation
4. To permit students to use this knowledge in describing a performance as part of their synoptic assignment

Tasks

In this study pack you will find a range of tasks that require the student to develop their knowledge of the terms and relationships involved in describing energy usage, muscle fatigue and water and temperature regulation.

Students will need to

1. Understand the terminology used to describe these physiological responses
2. Appreciate the relationship between intensity of exercise and energy sources
3. Understand the possible causes of muscle fatigue
4. Appreciate the effects of exercise on water and temperature regulation
5. Be able to apply these principles to observed performance

The difficulties encountered in this area of the specification are that there are no hard and fast rules that cover this area, only generalisations that need to be understood and adapted to suit individual requirements.

All the following tasks involved require the students to work either from the tasks as free-standing units, or to use the tasks as additional reinforcement and/or revision to class-delivered lessons.

Assessment of this work could simply be as answers to the posed questions, or assessed as part of a group's work, or through class discussion.

Task 1

Read through the following information, answering the questions posed in the spaces provided.

Muscle fatigue is defined as the inability to maintain or repeat the production of a given force by muscular contraction. Muscle fatigue is usually due to anaerobic exercise, but describing an exact cause has proved difficult.

Experiments have shown that fast-twitch fibres fatigue more easily than slow-twitch. The site of this fatigue appears to be the process of muscle contraction rather than any lack of nervous stimulation at the neuromuscular junction. It is suggested that the fatigue is linked to the lack of aerobic capacity of the fast-twitch fibres, and their high anaerobic capacity, and the corresponding build up of muscular and blood lactate concentrations.

a Explain what you understand by the terms aerobic capacity and glycolytic potential.

Aerobic capacity - ability to provide energy using oxidation of foods; glycolytic potential - ability to provide energy through anaerobic(without oxygen) mechanisms.

There is also evidence that it is the depletion of short-term energy stores, namely phosphocreatine and glycogen, that results in the exercising muscle fibres inability to replenish sufficient ATP quickly enough for muscle contraction.

In maximal or near-maximal exercise of short duration (less than 10 secs), the energy supply must be anaerobic, but it has been shown that in such exercises the demand for ATP is so great that it cannot be met by transferring ATP from stores or from phosphocreatine, and so the work must slow or stop, to allow ATP to be moved to the cross bridges.

When exercise lasts longer than 10 secs, up to 2 mins, there is a reduction in phosphocreatine stores, as well as a drop in ATP (approximately 30-40%). This reduction in ATP is quite large when it is realised that large amounts of ATP are unavailable for muscle contraction because of being stored in mitochondria and other compartments.

Hence at these workloads, it may be that phosphocreatine depletion is a major limiting factor in the ability of muscles to contract maximally.

Task 1 *continued*

b Under what circumstances could a lack of phosphocreatine be a cause of fatigue in exercising muscles?

When the intensity of the exercise is maximal,

or near maximal and lasts for about 10 seconds

It could also well be that lactate accumulation contributes to fatigue, because of its production during anaerobic glycolysis. Its presence causes a reduction of pH within the muscle fibres (high acidity), which leads to the reduced activity of certain enzymes (principally phosphofructokinase) involved in glycolysis.

Therefore, the replenishment of ATP by glycolysis may also be reduced when lactate builds up with strenuous exercise. Thus, for exhaustive exercise sustained between 10 secs and 2 mins, the likely cause of fatigue is phosphocreatine depletion and lactate accumulation.

Physical exercise sustained for 3-15 minutes does not seem to be limited by depletion of either ATP, phosphocreatine, or glycogen. Since neither blood glucose nor fat make significant contributions to exhaustive activity lasting less than 15 minutes, it may be assumed that it is lactate accumulation that is the limiting factor.

c Suggest under what circumstances lactate accumulates.

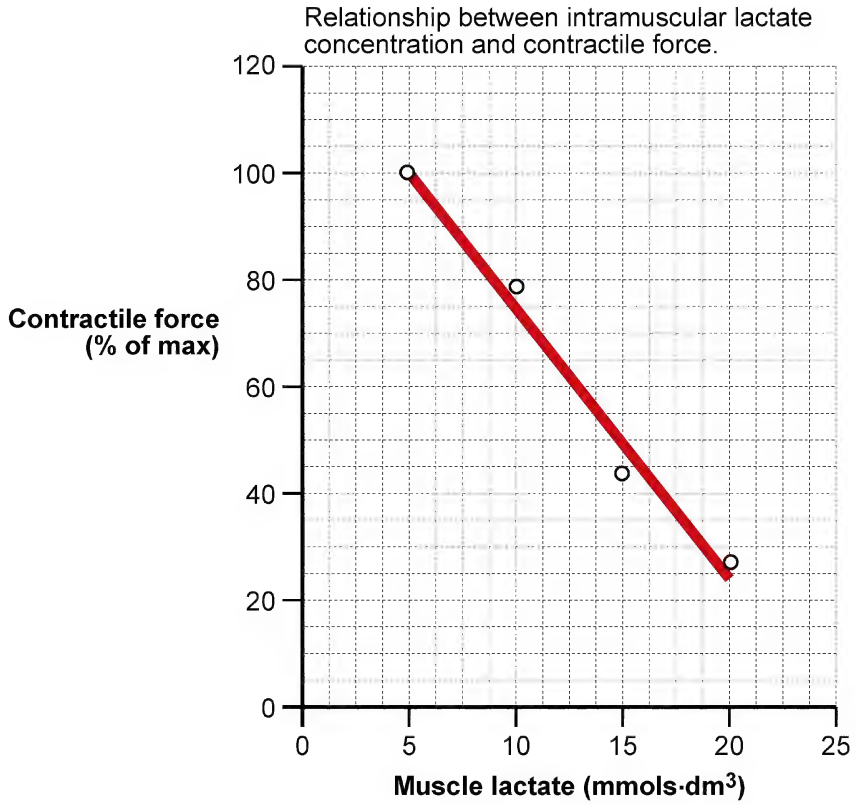
Anaerobic glycolysis occurs during intense

prolonged exercise production is faster than removal,

and this leads to the accumulation of lactate

Task 1 *continued*

d Study and comment on the following graph.



There is a close relationship between the rate of accumulation of lactate and intensity of muscle contraction, confirming the idea of lactate being a cause of fatigue

The effects of lactate accumulation is the result of excess concentrations of hydrogen ions (H^+), which lowers pH within the muscle. One of the effects of this is to decrease the binding of calcium to troponin, thereby reducing the activation of actin-myosin cross bridges in muscle contraction. Also, it has been found that if body fluid pH is made more acidic artificially, then exercise endurance in reduced, but if an alkali is used to raise body pH, then endurance is increased (a technique known as soda loading).

Task 1 *continued*

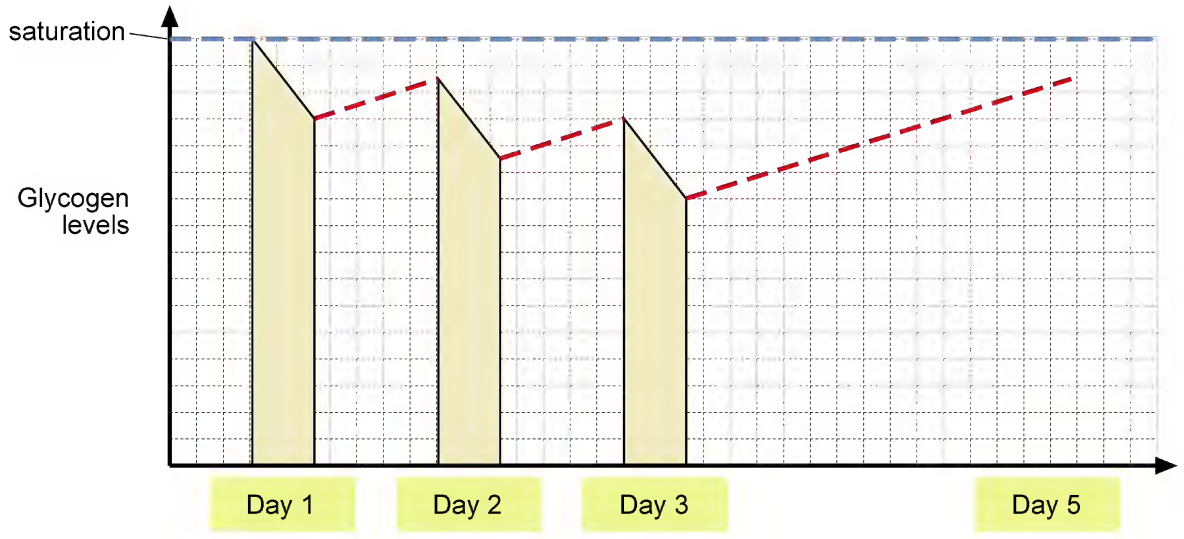
e Suggest how lactate accumulation is a direct cause of fatigue.

Increasing acidity (lower pH) decreases the binding of calcium to troponin, and may also reduce the activity of glycolytic enzymes

In longer term exercise, lasting 15-60 mins, it is thought that it is a combination of lactate accumulation, some depletion of glycogen, and an increase in body temperature that causes fatigue.

When the exercise lasts 1-4 hours, it is probable that it is the depletion of glycogen stores that causes fatigue. It is also possible that dehydration in this type of activity, may lead to a failure in temperature regulation, leading to fatigue before glycogen stores are depleted.

f Study and comment on the following graph



Glycogen stores within the body are depleted by each successive run, and never return to their pre-exercise levels before next days exercise begin. Even two days of recovery are insufficient to fully replenish glycogen stores

Task 2

Read the following piece of information, answering the questions in the spaces provided.

In attempts to provide themselves with greater stores of glycogen, and hence greater stores of energy, elite endurance athletes may try to manipulate their diet and carbohydrate intake/exercise regime, commonly called **glycogen** or **carbohydrate loading**.

There are two common methods to achieve extra glycogen stores. The original method, dating from the 1970's involves undertaking exhaustive exercise approximately seven days prior to competition in order to deplete glycogen stores.

Following this the dietary intake is restricted for 4-5 days in terms of carbohydrate to ensure that glycogen stores are kept low. A further exhaustive run 2 days before competition is followed by a high carbohydrate diet 24 hours before the competition, essentially to fool the body into storing more glycogen than it normally does.

A more recent development has been an alternative method that does not involve such an exhaustive regime. Normal training is followed for the seven days prior to the competition, and this coincides with a diet that restricts carbohydrate intake. This depletes the muscle glycogen stores. Then 24 hours prior to competition a high carbohydrate diet is consumed, so artificially increasing the glycogen stores ready for the event.

a Explain the theory and practicalities of glycogen loading

Deplete glycogen stores through exercise and/or diet, then permit body to overcompensate through excess intake of carbohydrate

Task 2 *continued*

Muscle contractions generate large amounts of heat, but the body needs to maintain constant body temperature. Hence, during exercise there is a need to lose the excess heat produced.

This is mainly achieved through sweating. Sweat evaporates from the skin's surface, and this process cools the body. Sweating is a constant process; we sweat continually to control our body temperature. We don't see the effects because the sweat evaporates.

This process becomes difficult if the environmental humidity becomes high, the result being a very high body temperature which leads to heat stroke.

Body temperature is also reduced through a process where the blood that has become warmer due to exercise generating heat is redirected. The blood capillaries near skin's surface open, causing the characteristic red face in fair-skinned peoples. The heat contained in the blood is then lost through radiation. This process becomes difficult the closer the environmental temperature becomes to the body temperature.

A consequence of sweating is that not only is the body cooled, but water is also lost. A loss of 3-4 litres per hour possible, and hence there is need to replace the lost fluids. As a general rule, any activity lasting over 1 hour needs fluid replacement, and as a rough guide, 250cm^3 per hour would appear to be suitable, but in warmer/more humid conditions, more intake is needed.

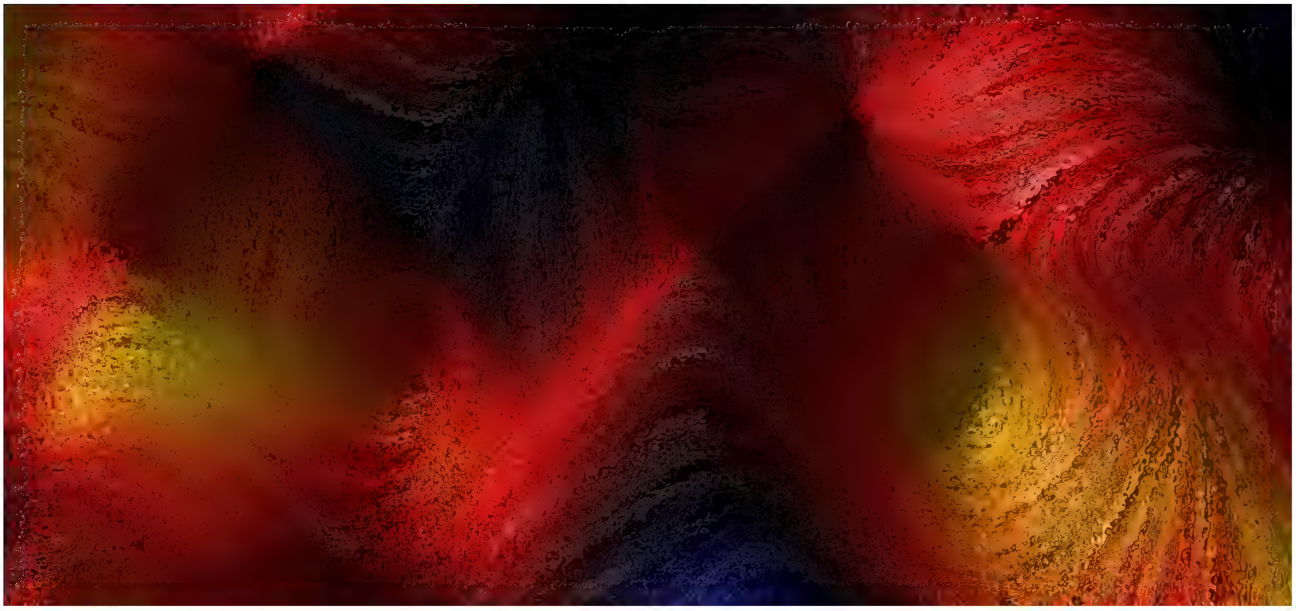
b Explain how the body regulates its temperature and the consequences of this process.

Sweating – water evaporating from skin's surface cools body, as does loss of heat from surface blood capillaries through radiation. Sweating means water loss, which needs replacement to avoid consequences in long duration activities, especially those undertaken in high humidity or temperature environments

Teaching Resource

Part 3 Energy Concepts

C ATP-PC system



Feltham Press

General Considerations and Objectives

1. To allow students to understand and use appropriate terminology to describe energy production using the ATP-PC system
2. To enable students to appreciate the essential role of this system in certain types of performances

Tasks

In this study pack you will find a range of tasks that require the students to develop their knowledge of the terms and relationships involved in describing energy production through the ATP-PC system.

Students will need to

1. Understand the essential terminology used to describe energy production in the form of ATP
2. Appreciate role of phosphocreatine as a store of potential energy for release during short duration, intense exercise
3. Be able to apply these principles to observed performance

The concepts of energy systems (bioenergetics) are quite difficult to understand for many, as their mechanisms involve complicated chemistry. The role of the teacher here is to simplify (as best as possible) the processes involved so that students have sufficient understanding to explain the use of the ATP-PC energy system during specific performances.

All the tasks involved require the students to work either from the tasks as free-standing units, or to use the tasks as additional reinforcement and/or revision to class-delivered lessons.

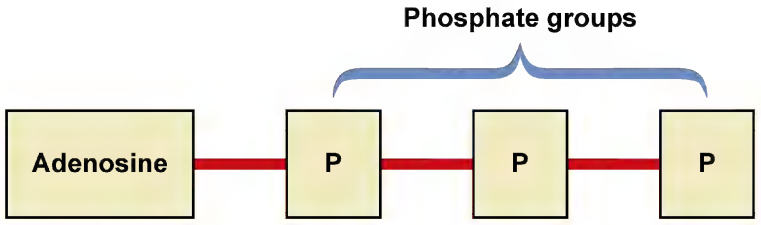
Assessment of this work could simply be as answers to the posed questions, or assessed as part of a group's work, or through class discussion.

.

Task 1

Read through the following information, answering the questions in the spaces provided.

The energy we need for muscle contractions supplied in the form of food, which is broken down within cells to release **chemical energy**. The immediately (directly) usable form of chemical energy for muscular activity is **adenosine triphosphate (ATP)**.

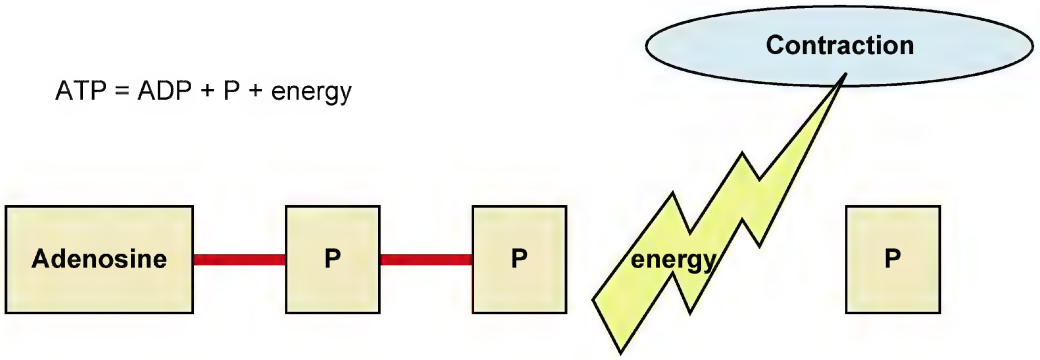


It is the body's job to transfer the chemical energy stored in food into the usable energy found in ATP. Energy is released when ATP is broken down, and energy is required to rebuild (resynthesise) it.

The breakdown of ATP releases **adenosine diphosphate (ADP)** and **phosphate (P)**.

The body then rebuilds (resynthesises) ATP from the breakdown products using energy from respiration:

ADP + P + energy = ATP



Whenever we use ATP to supply the energy we need, we have to immediately resynthesise it.

Hence when a muscle fibre uses ATP to supply the energy for the fibre to contract, that ATP has to be resynthesised immediately.

Task 1 *continued*

a Describe in your own words how ATP is broken down and later resynthesised.

ATP is broken down to ADP and phosphate and the released energy used for muscle contraction. Resynthesis of ATP also requires energy to recombine ADP and phosphate.

We resynthesise ATP from three different series of chemical reactions that take place within muscle cells (for example). Two depend on the food we eat, whilst the third relies on a chemical called **phosphocreatine**.

As soon as ATP is synthesised, it is used to supply energy, and as soon as it supplies energy, it is resynthesised. We are concerned primarily with the reactions involved in energy storage and utilisation that allow an athlete to perform adequately.

During high intensity activity, ATP is used up at a faster rate than it can be produced aerobically. In this "emergency" situation, where the rapid renewal of ATP is important, another energy-rich compound, **phosphocreatine** (**PC**), is used to provide the energy required for ATP resynthesis. Hence, we use this system of re-synthesising ATP when we are involved in 'all-out' intensive effort.

PC is stored in muscles, and when it is broken down, a large amount of energy is released that can be used for ATP resynthesis. The breakdown of PC releases creatine and phosphate (P):

PC = creatine + P + energy

The released energy is then used to resynthesise ATP:

ADP + P + energy = ATP

In other words, as rapidly as ATP is broken down during muscular contraction, it is continuously reformed from ADP and phosphate by the energy released during the breakdown of the stored PC.

Task 1 *continued*

b Explain in your own words the role of phosphocreatine in providing energy for muscle contraction.

Phosphocreatine is broken down to produce creatine and phosphate, and at the same time energy is released which is then used to convert ADP and phosphate into ATP.

The capacity to provide sufficient energy for ATP resynthesis by this process is limited to a very short duration, lasting only a few seconds. In all-out sprint efforts or rapid, high-intensity, repetitive exercises, PC concentrations drop to very low levels within a few (6-10) seconds, resulting in fatigue. However, PC stores are quickly regenerated to near normal levels within a few minutes of stopping exercise.

The usefulness of this system of energy production lies in the availability of **immediate** supplies of energy for ATP resynthesis, and the **rapid recovery**, within 3-4 minutes, of PC levels once exercise has ceased.

c Describe three different activities where ATP-PC will be the predominant energy system being used

The ATP-PC system is the predominant energy system used in intense short duration activities such as 60 metre sprinting, shot put, weight-lifting, javelin throwing etc.

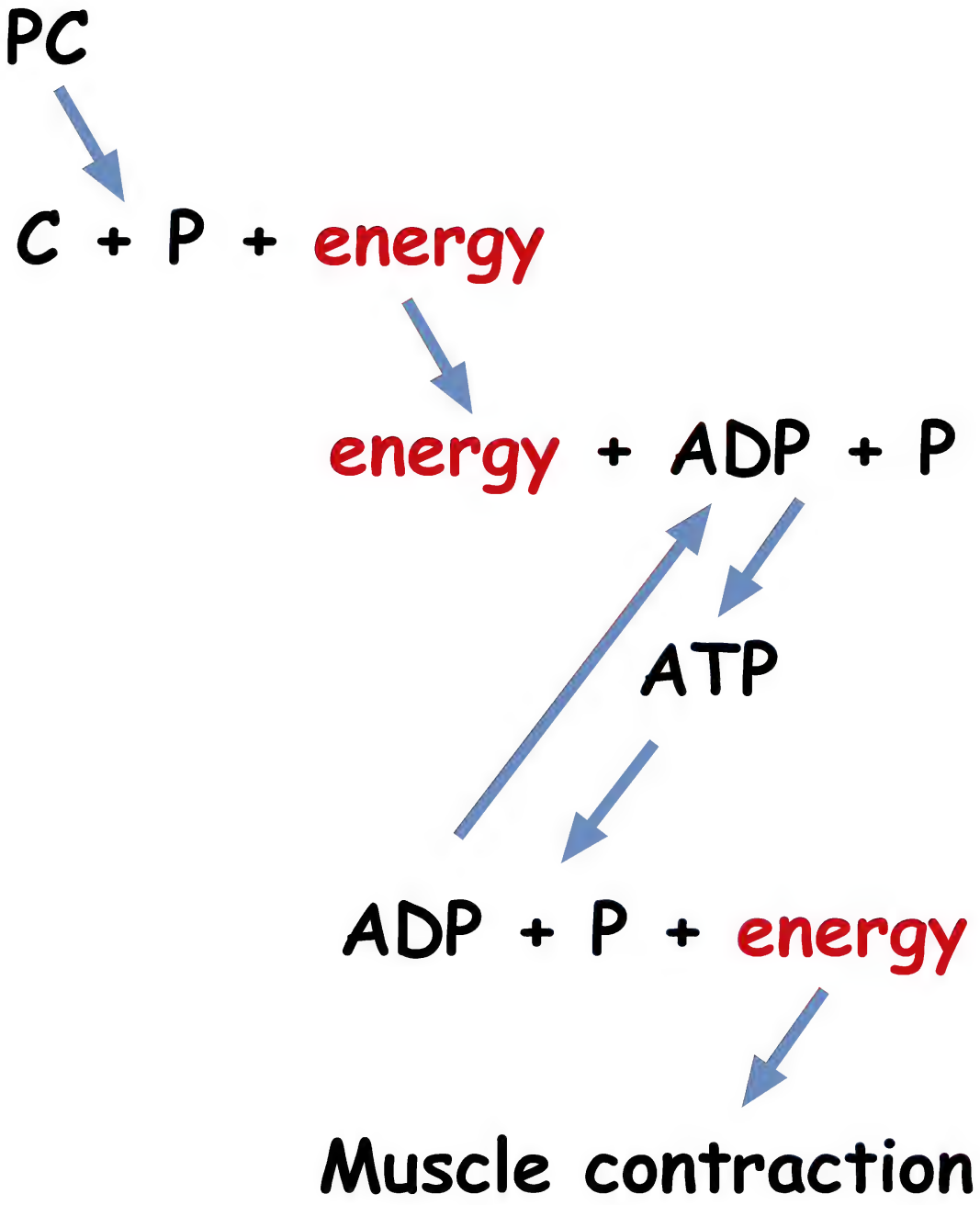
d Describe three aspects of one activity where the ATP-PC system would be the predominant provider of energy.

In a game, the ATP-PC system would be used in such things as sprinting, jumping, kicking, etc

Task 2

Produce a poster, OHT or PowerPoint presentation that summarises the role of the ATP-PC system in providing energy to muscles.

PC
C + P + energy
energy
ATP
ADP + P
Muscle contraction
(some terms can be used more than once)

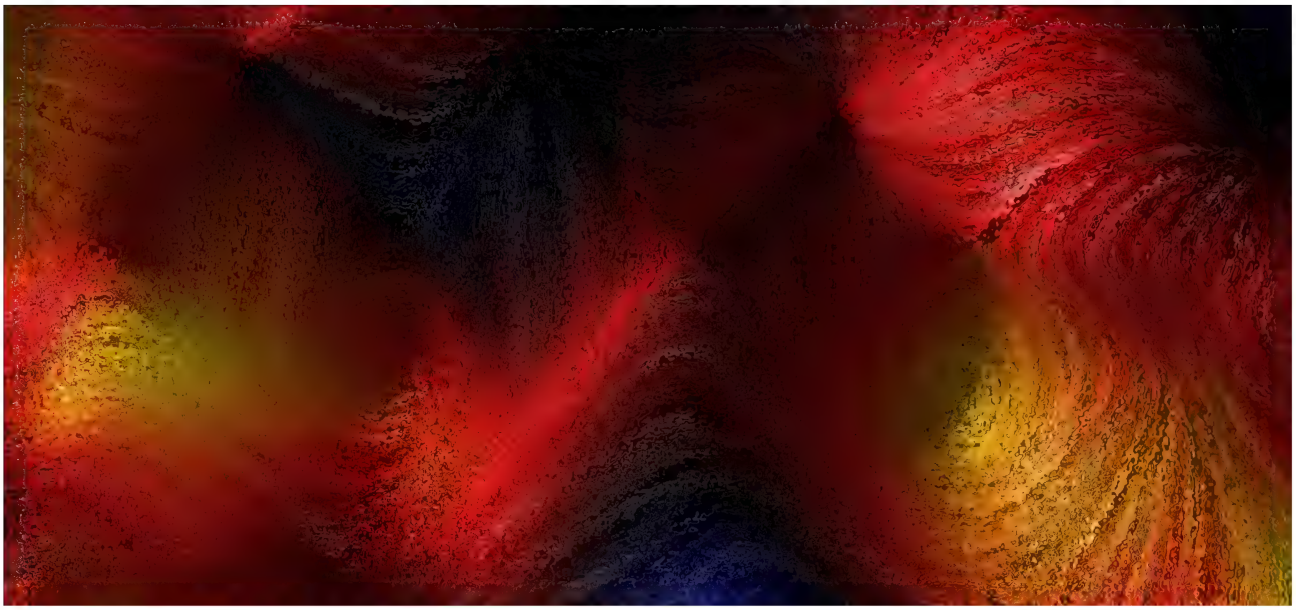


Teaching Resource

Part 3 Energy Concepts

D Lactate

Anaerobic system



Feltham Press

General Considerations and Objectives

1. To allow students to understand and use appropriate terminology to describe energy production using the lactate anaerobic system
2. To enable students to appreciate the essential role of this system in certain types of performances

t

Tasks

In this study pack you will find a range of tasks that require the student to develop their knowledge of the terms and relationships involved in describing energy production through the lactate anaerobic system.

Students will need to

1. Understand the essential terminology used to describe anaerobic energy production in the form of ATP
2. Appreciate role of glycogen as a store of potential energy for release during medium duration, intense exercise
3. Understand the circumstances involved, and difficulties encountered in using the lactate anaerobic system
4. Be able to apply these principles to observed performance

The concepts of energy systems (bioenergetics) are quite difficult to understand for many, as their mechanisms involve complication chemistry. The role of the teacher here is to simplify (as best as possible) the processes involved so that students have sufficient understanding to explain the use of the lactate anaerobic energy system during specific performances.

One of the major problems for students is the regular usage of alternative names (anaerobic glycolysis, lactic acid system, etc) for this system. It is advisable for the teacher to limit themselves to one name, and require the examinations board to provide the alternative, but note that the specification describes this system as the lactic anaerobic system, and talks of the anaerobic break down of glycogen.

All the tasks involved require the students to work either from the tasks as free-standing units, or to use the tasks as additional reinforcement and/or revision to class-delivered lessons.

Assessment of this work could simply be as answers to the posed questions, or assessed as part of a group's work, or through class discussion.

There is no need for detailed knowledge of the biochemistry of energy systems to be delivered or understood

Task 1

Read through the following information, answering questions in the spaces provided.

The breakdown of the energy substrate glycogen is called glycolysis. During glycolysis, glycogen is first converted to glucose and then broken down to pyruvate (pyruvic acid). This process takes place in the sarcoplasm of muscle fibres and does not require the presence of oxygen; it is an anaerobic process. Hence **anaerobic glycolysis**.

This system is the primary source of energy and ATP when exercise continues at a high intensity, as for example when the athlete continues strenuous activity over a period of 30 or more seconds. In this system, the partial breakdown of carbohydrate (glucose) to pyruvate, provides the energy for ATP resynthesis.

a Describe in your own words the anaerobic breakdown of glycogen.

Glycogen is converted into glucose and then broken down into pyruvate in the muscle fibre's sarcoplasm. This anaerobic process results in the release of ATP, which may then be used for muscle contraction

In the presence of oxygen, the two molecules of pyruvate formed from glucose is further broken-down into carbon dioxide and water, but when the demand for energy from ATP exceeds normal glycolytic and oxidative rates, then pyruvate is temporarily converted to **lactate**. In other words if too much pyruvate is being produced, not all of it can be broken down aerobically, and some is converted into lactate.

b Explain why lactate is formed during intense exercise.

During intense exercise the rate of production of pyruvate exceeds its rate of breakdown. The excess pyruvate is converted into lactate

Task 1 *continued*

The lactate being produced first accumulates in the muscles, but then is diffused into the blood. High levels of lactate in the muscles causes fatigue. In such circumstances, exercise must be lessened or stopped to allow the body to remove the lactate.

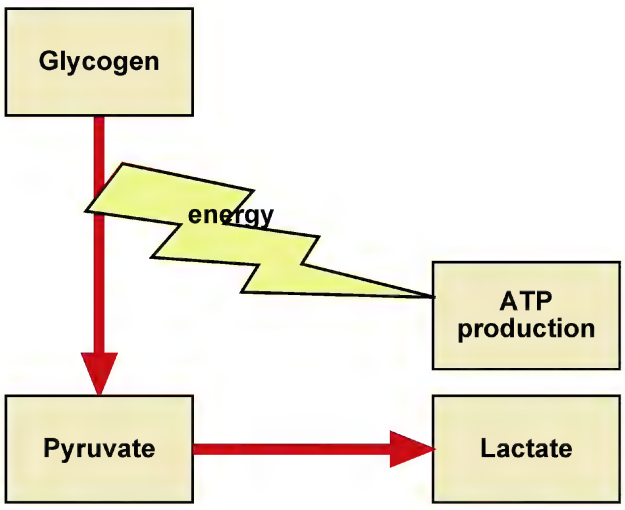
c Suggest a cause and a reason for fatigue due to lactate accumulation.

Lactate accumulation occurs as a result of exercise of high intensity causing excess pyruvate being converted into lactate. This in turn is thought to increase the acidity within muscles (lowers pH) which inhibits muscle contraction

Another limitation of this system is that only a relatively small amount of ATP can be produced from anaerobic glycolysis. The lactate anaerobic system, like the ATP-PC system, is extremely important to the athlete, because it also provides a rapid supply of resynthesised ATP for energy. For example, exercises performed at near-to-maximum rates and lasting about 2 minutes depend heavily upon the lactate anaerobic system to provide ATP energy.

Also, in many events, the "sprint finish" relies on the lactate anaerobic system for its energy supply.

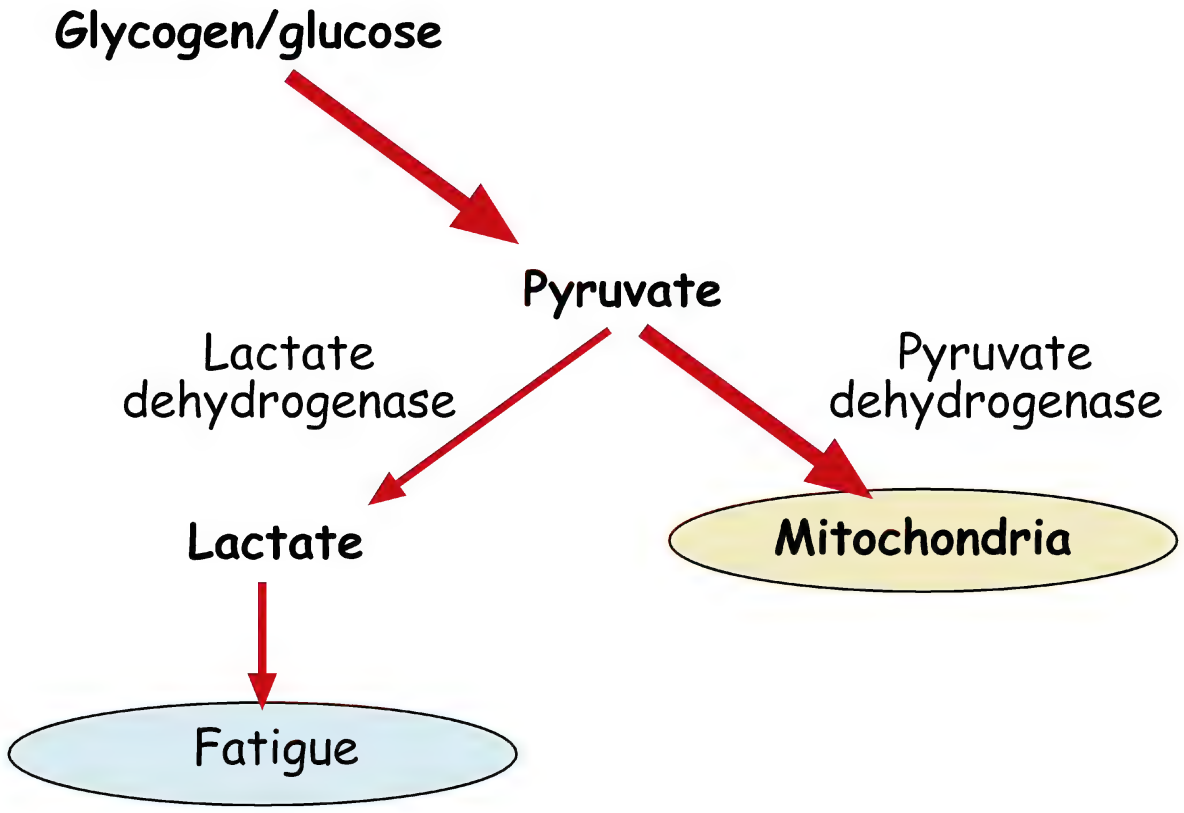
The following diagram summarises the lactate anaerobic system:



Task 2

Produce a poster, OHT or PowerPoint presentation that summarises the role and the circumstances of the lactate anaerobic system in providing energy to muscles.

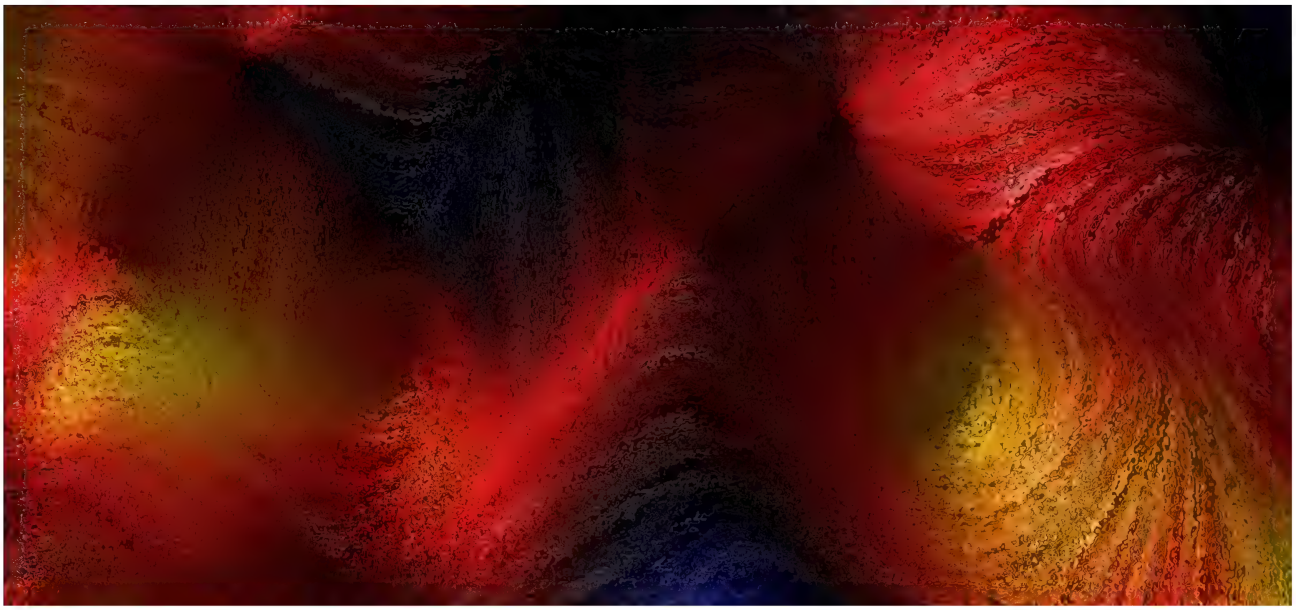
Pyruvate
Fatigue
Glycogen/glucose
Lactate
Pyruvate dehydrogenase
Lactate dehydrogenase



Teaching Resource

Part 3 Energy Concepts

E Aerobic systems



.

Feltham Press

General Considerations and Objectives

1. To allow students to understand and use appropriate terminology to describe energy production using the aerobic system
2. To enable students to appreciate the essential role of this system in certain types of performances
3. To permit students to use this knowledge in describing a performance as part of their synoptic assignment

Tasks

In this study pack you will find a range of tasks that require the students to develop their knowledge of the terms and relationships involved in describing energy production through the aerobic system.

Students will need to

1. Understand the essential terminology used to describe aerobic energy production in the form of ATP
2. Appreciate role of glycogen and fat as stores of potential energy for release during long duration, low intensity exercise
3. Be able to apply these principles to observed performance

The concepts of energy systems (bioenergetics) are quite difficult to understand for many, as their mechanisms involve complication chemistry. The role of the teacher here is to simplify (as best as possible) the processes involved so that students have sufficient understanding to explain the use of the aerobic energy systems during specific performances.

All the tasks involved require the students to work either from the tasks as free-standing units, or to use the tasks as additional reinforcement and/or revision to class-delivered lessons.

Assessment of this work could simply be as answers to the posed questions, or assessed as part of a group's work, or through class discussion.

There is no need for detailed knowledge of the biochemistry of energy systems to be delivered or understood

Task 1

Read through the following notes, answering the questions in the spaces provided.

In the presence of oxygen, muscle glycogen can be completely broken down into carbon dioxide and water, whilst at the same time releasing energy for ATP synthesis.

The series of reactions involved are, unlike the anaerobic processes, confined to specialised organelles, the **mitochondria**. These are often called the 'powerhouses' of cells, because they are the site of the aerobic manufacture of ATP. As should be expected, muscle fibres are rich in mitochondria.

Aerobic systems use either fat or glucose as the starting point for energy, and produce carbon dioxide and water as waste products. The aerobic production of ATP has several advantages over the anaerobic systems:

1 there are no fatiguing by-products;

2 the starting chemicals are in abundant supply, and are rarely exhausted;

3 far more ATP is produced from aerobic metabolism than can be produced from anaerobic metabolism.

a Describe the role of mitochondria in energy production.

Mitochondria are the organelles found in muscle fibres (and most other cells) where most ATP is formed from the break down of chemicals

Task 1 *continued*

b What do you understand by the term aerobic metabolism?

Series of chemical reactions that involve oxygen

c What are the advantages of using aerobic mechanisms to produce energy?

No waste products causing fatigue; rich supply of starting products; more energy produced than from anaerobic mechanisms.

Glucose that is derived from carbohydrates in the diet, is stored in muscle (and liver) as glycogen (long chains of glucose units). The glycogen is then broken down to glucose as needed.

d What do you understand by the term glycolysis?

The break down of glycogen and/or glucose to pyruvate with the release of some energy for the synthesis of ATP. It is an anaerobic process

The simple difference between aerobic respiration and anaerobic respiration is that in the latter, the end product is fatigue-causing lactate, whilst in the former, the presence of oxygen, allows the complete oxidation of glucose to carbon dioxide and water in the mitochondria (see later).

In other words, in the presence of adequate oxygen, there is no build up of lactate, because the pyruvate is directed into the aerobic pathway. Aerobic glycolysis takes place initially in the sarcoplasm of muscle cells, and then finally in the mitochondria.

e Compare anaerobic respiration with aerobic respiration.

The processes differ in their end products – aerobic respiration leads to the pyruvate being further broken down in the mitochondria with further energy release; in anaerobic respiration, the pyruvate is converted to a fatigue-causing end product called lactate

The pyruvate formed during aerobic respiration is added to an enzyme to allow it to enter the mitochondria. The pyruvate becomes converted into carbon dioxide and water, and large amounts of energy are released in the form of ATP. This process requires large amounts of oxygen for its completion.

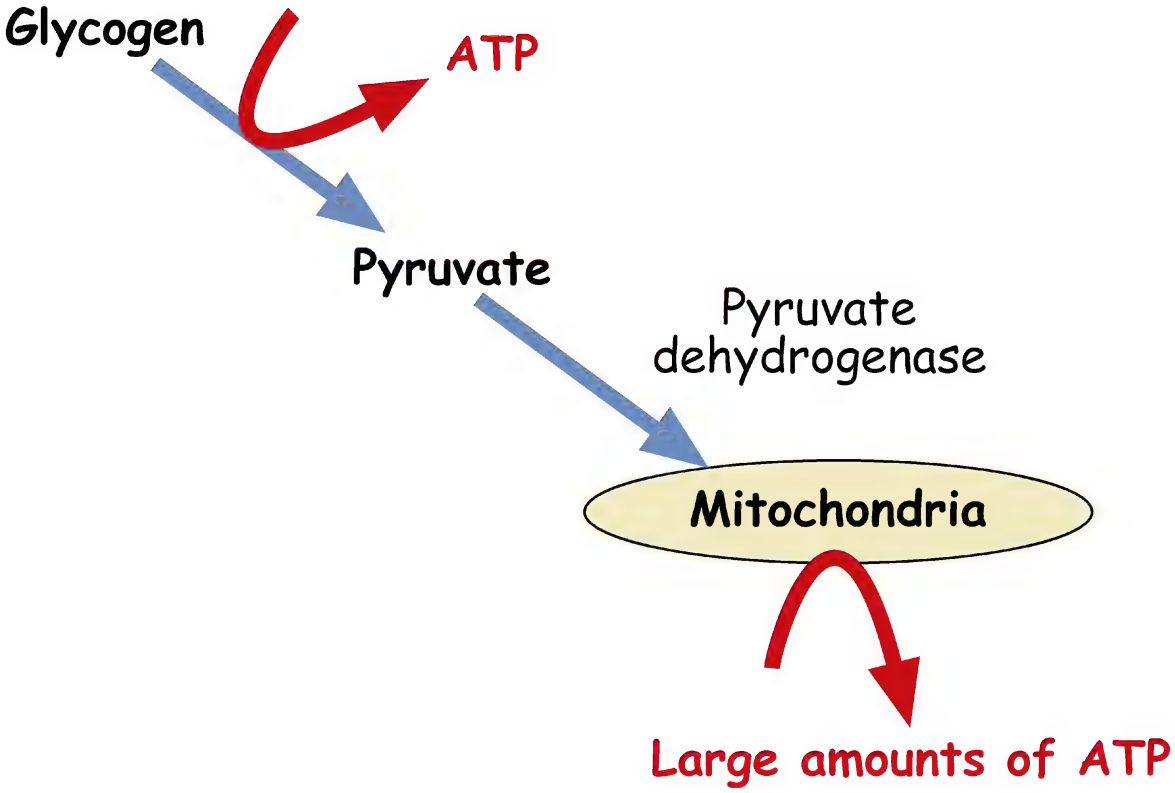
f Summarise the role of oxygen in aerobic energy production.

Oxygen is needed to convert the pyruvate into carbon dioxide and water.

Task 2

Produce a poster, OHT or PowerPoint presentation that summarises the conversions that occur when the aerobic system is providing energy to muscles.

Pyruvate
Glycogen
ATP
Pyruvate dehydrogenase
Mitochondria
Large amounts of ATP



Task 3

Read through the following notes, answering the questions in the spaces provided.

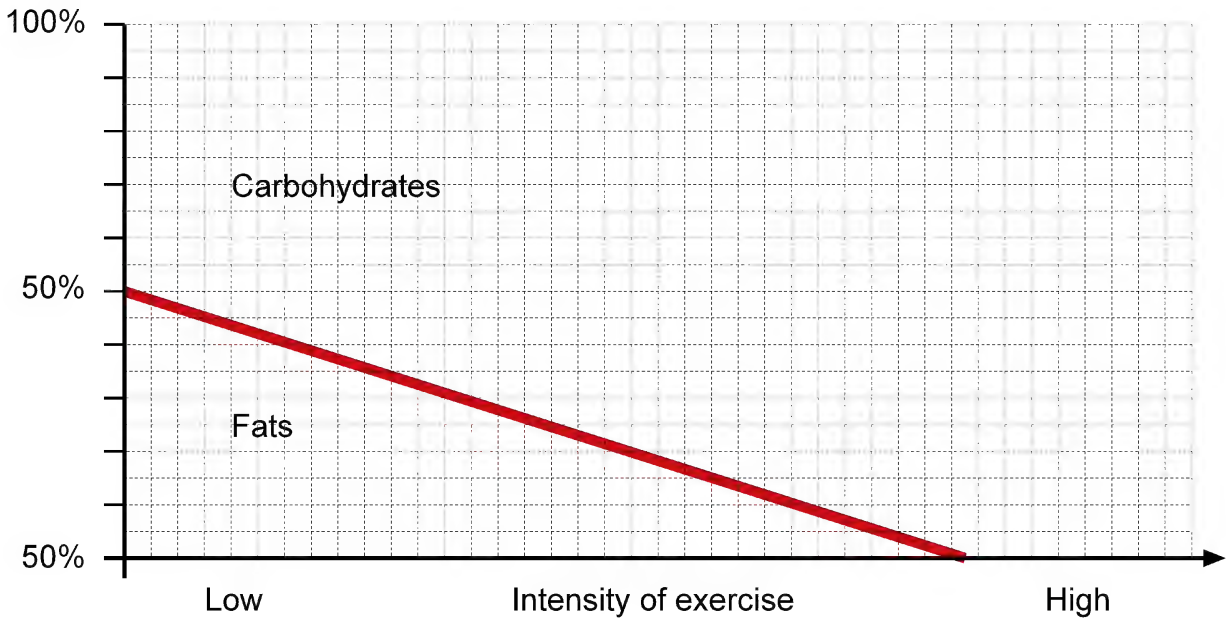
At rest, approximately a half to two-thirds of our energy requirements comes from fat metabolism, and only a half to one-third from carbohydrates. During exercise, the reliance on fats diminishes dramatically in explosive sports, but in endurance events, the mixed utilisation of fats and carbohydrates becomes important. The 'mix' of food fuels depends upon the **intensity** and the **duration** of the exercise, the athlete's level of **conditioning**, and the athlete's **diet and nutritional status**.

a Describe how the proportions of fat and carbohydrate used during exercise and rest varies.

At rest, fat may provide up to 50-60% of our total energy demand; as the intensity of the exercise increases, so does the proportion of carbohydrate being used. At intense levels of exercise, all the energy is supplied through carbohydrate

Task 3 *continued*

b Draw a graph that shows how the proportions of fat and carbohydrate being used varies with the intensity of exercise.



All fat in our diet is primarily carried in the blood as 'free' fatty acids. The first stage of fat breakdown 'prepares' the fatty acid for entry into the mitochondria. Once in the mitochondria, the final result is the same as for glycogen; i.e., water and carbon dioxide are produced and energy is liberated for the synthesis of ATP.

c What does the first stage of fat breakdown do?

Fatty acids are prepared for entry into the mitochondria

d What are the end-products of the aerobic break down of fats?

Carbon dioxide and water - same as produced from carbohydrates

Task 3 *continued*

The use of fats for energy relies on adequate supplies of oxygen - it is an aerobic process. Fats cannot be broken-down anaerobically. The use of fats by the body thus ultimately depends on the body's ability to supply oxygen to the working muscles. If exercise is primarily aerobic, involving slow continuous activity (lasting at least an hour), then fat is the main substrate used, and the majority of our energy is derived from fats.

However, fat breakdown requires more oxygen than glucose breakdown. Therefore, when oxygen supply becomes a limiting factor, as occurs during intensive exercise, glucose becomes the preferred fuel. Exercise at close to $\dot{V}O_2$ max therefore uses glucose as the main fuel source. Appropriate training increases body's the ability to take in oxygen to the muscles, and thus increases the ability to use fat for energy.

Fat would appear to be an ideal respiratory substrate, but it should be remembered that fat is not available for anaerobic work, and therefore cannot be used for fast, explosive exercise. Also, fat stores might have value as an energy source, but they are also contribute to excess non-functional weight, which will cause a relative increase in the amount of energy required for the completion of a given task.

e Explain why fat cannot be used as an energy source during intense exercise

Because at high intensity oxygen supplies become limited and fat has a higher demand for oxygen than carbohydrate, and therefore glycogen becomes the preferred energy source. Also fat cannot be broken down anaerobically, whereas carbohydrate can.

Task 3 *continued*

Only a relatively small amount of fat is stored in muscles as triglycerides, hence it is the free fatty acids that are circulating in the blood that are the main reservoirs for fat supplies for energy in muscles. When these are being used, triglyceride stores in the adipose tissue are mobilised to release free fatty acids into the blood plasma, which are then transported to the working muscles.

Endurance training increases the body's ability to release free fatty acids from their fat stores, and this is one of the reasons that the trained can utilise more fats for energy than the unfit. If not used, the free fatty acids can be resynthesised into fats and stored in adipose tissue.

Remember that the breakdown of fats requires the presence of carbohydrates, because without carbohydrates, the mitochondria will not operate. Therefore, if energy demand remains high during prolonged, continuous exercise, carbohydrate (glycogen) stores become depleted, and the breakdown of fats will slow because of the lack of carbohydrates.

Fat reserves also constitute an insulating layer beneath the skin, which acts as a barrier to heat loss and can thus prevent the heat that is generated through exercise, being dissipated. Excess fat can restrict joint movement.

f What are the disadvantages of using fat as an energy substrate, and having excess fat stores?

Cannot be used at high intensity; stores constitute unnecessary excess weight that limits endurance; fat may limit mobility; fat stores may limit heat loss mechanisms

It must be appreciated that the three energy systems described above do not work in isolation. There is no switching from one system to another. Energy supply is suited to demand.

In terms of performance, if energy demand is great, the ATP-PC system provides the majority of the ATP resynthesis.

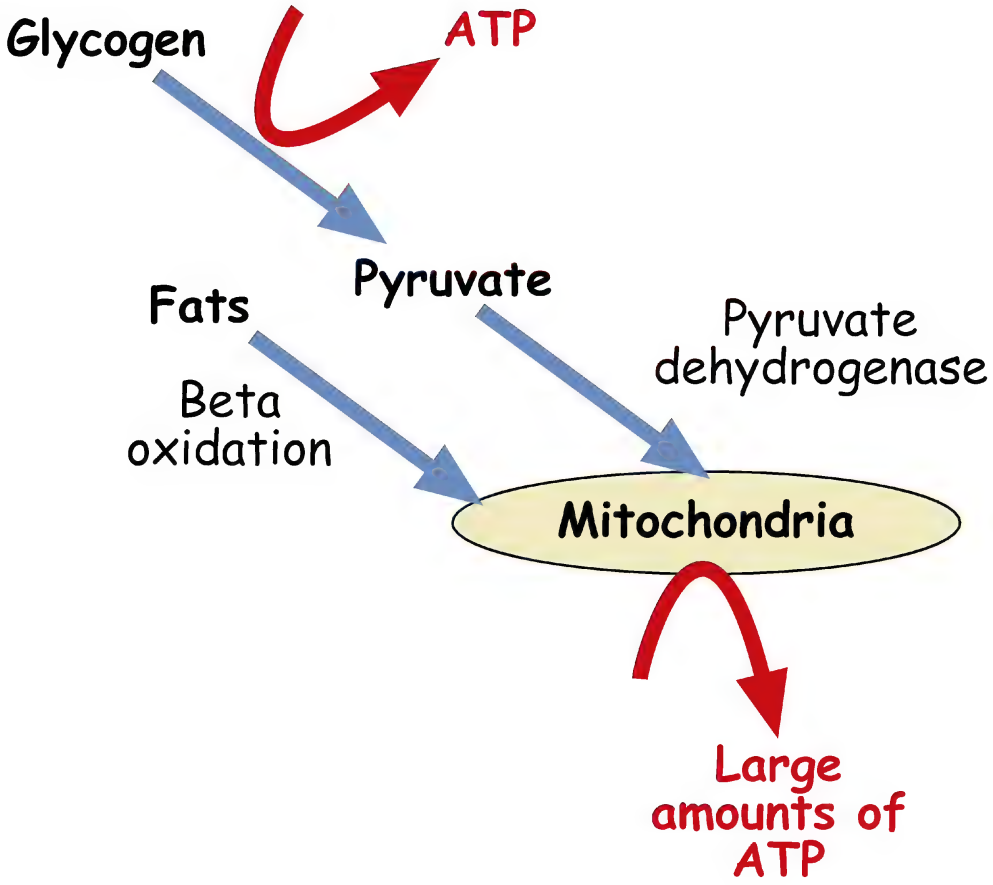
If exercise continues at a high rate, the **majority** of ATP comes via the lactate anaerobic system, whilst if the exercise becomes long duration, the aerobic system provides the majority of the ATP.

Thus it is common to describe activities by the predominant energy system involved - thus long duration, low intensity activities are termed aerobic, whilst explosive short duration activities are termed anaerobic.

Task 4

Review the poster, OHT or PowerPoint presentation that summarised the role and the circumstances of the aerobic system in providing energy to muscles in Task 2, and add fat metabolism to the poster, OHP or PowerPoint presentation, using the terms;

Fats
Beta oxidation



Teaching Resource
Performance Criteria

A Excess Post-exercise Oxygen Consumption

Feltham Press

General Considerations and Objectives

1. To allow students to understand and use appropriate terminology to describe the recovery process
2. To enable students to appreciate the essential role of this system in the restoration of pre-exercise metabolic levels

Tasks

In this study pack you will find a range of tasks that require the students to develop their knowledge of the terms and relationships involved in describing Excess Post-exercise Oxygen Consumption (EPOC).

They will need to

1. Understand and use the essential terminology used to describe EPOC
2. Appreciate the role of the fast and slow components of EPOC in restoring normal metabolic levels
3. Be able to apply these principles to observed performance

The concepts of EPOC are relatively straightforward for the student to understand. The role of the teacher here is to explain the processes involved so that students have sufficient understanding to explain the role of EPOC resulting from specific performances.

All the tasks involved require the students to work either from the tasks as free-standing units, or to use the tasks as additional reinforcement and/or revision to class-delivered lessons.

Assessment of this work could simply be as answers to the posed questions, or assessed as part of a group's work, or through class discussion.

Tthat there is no need for detailed knowledge of the biochemistry of energy systems to be delivered or understood.

Task 1

Read through the following materials, completing the work required.

When we exercise, and even when we are at rest, our bodies are using oxygen to release energy. The amount of oxygen used by our bodies to produce this energy is called our **oxygen uptake** or **oxygen consumption**.

When we begin to exercise, we need more energy and therefore use more oxygen; our oxygen consumption increases. Oxygen consumption is usually abbreviated to $\dot{V}O_2$.

The term **maximal oxygen consumption** (**$\dot{V}O_2$ max**) is used to refer to the maximum amount of oxygen that an individual can consume during strenuous exercise.

$\dot{V}O_2$ max varies considerably across individuals, ranging from 2 - 3 dm^3 per minute of O_2 in sedentary unfit women to values in excess of 10 dm^3 per minute of O_2 in trained endurance athletes

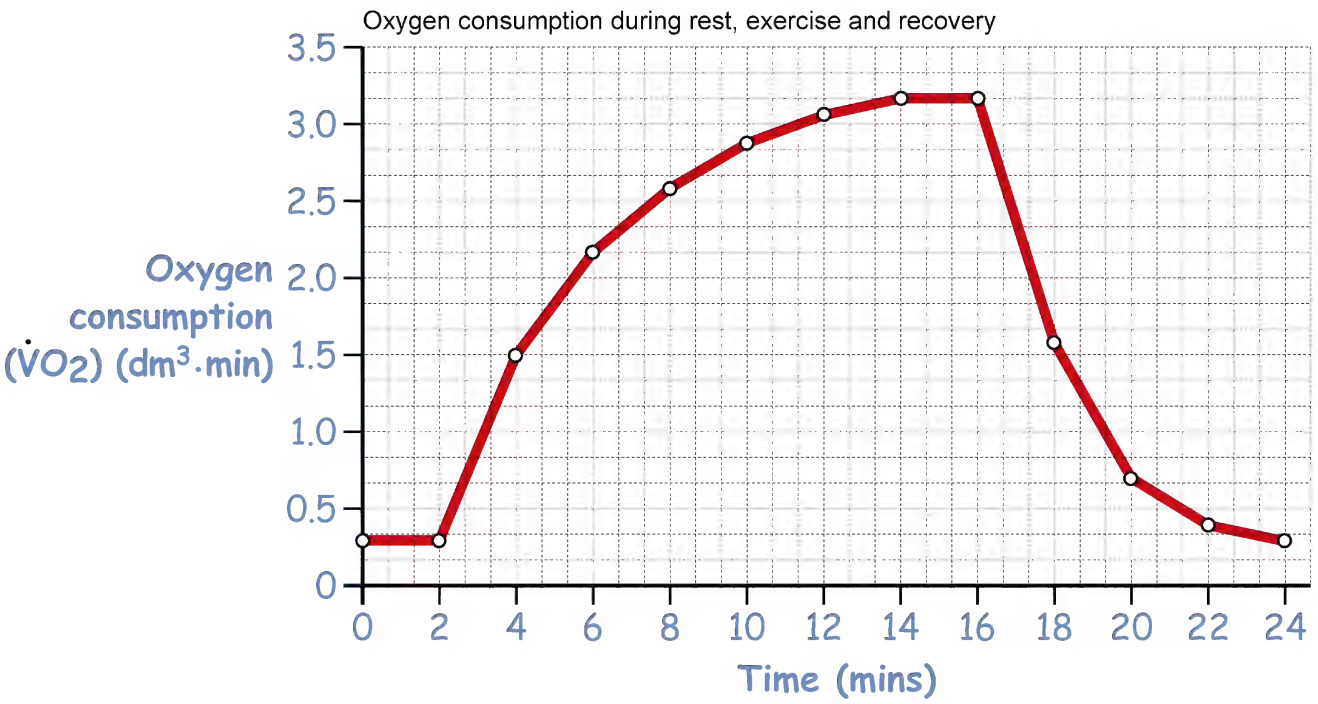
Because oxygen consumption depends on so many factors, including fitness, weight, percentage body fat, etc., it is quite common to see $\dot{V}O_2$ max measured in cm^3 per kg per min

A typical recording of an individual's oxygen consumption during rest, exercise and recovery, are shown below:

Activity	Time (mins)	Oxygen uptake ($dm^3 \cdot min^{-1}$)
Rest	0	0.30
Rest	2	0.30
Exercise	4	1.60
Exercise	6	2.40
Exercise	8	2.80
Exercise	10	3.00
Exercise	12	3.10
Exercise	14	3.20
Exercise	16	3.20
Recovery	18	1.60
Recovery	20	0.70
Recovery	22	0.40
Recovery	24	0.30

Task 1 *continued*

a Draw a graph of these results.



b What was the resting $\dot{V}O_2$, and the maximal exercising $\dot{V}O_2$?

Resting = 0.3 $dm^3 \cdot min^{-1}$; maximal = 3.2 $dm^3 \cdot min^{-1}$

c What is the oxygen consumption after 5 minutes and after 19 minutes?

After 5 minutes - $\dot{V}O_2$ = 1.8 $dm^3 \cdot min^{-1}$;

after 19 minutes - $\dot{V}O_2$ = 1.2 $dm^3 \cdot min^{-1}$

As can be seen from the graph, after exercise, bodily processes do not immediately return to their resting levels, especially if the exercise has been stressful. Recovery from exercise is largely associated with restoring the status quo as far as energy systems are concerned.

Task 2

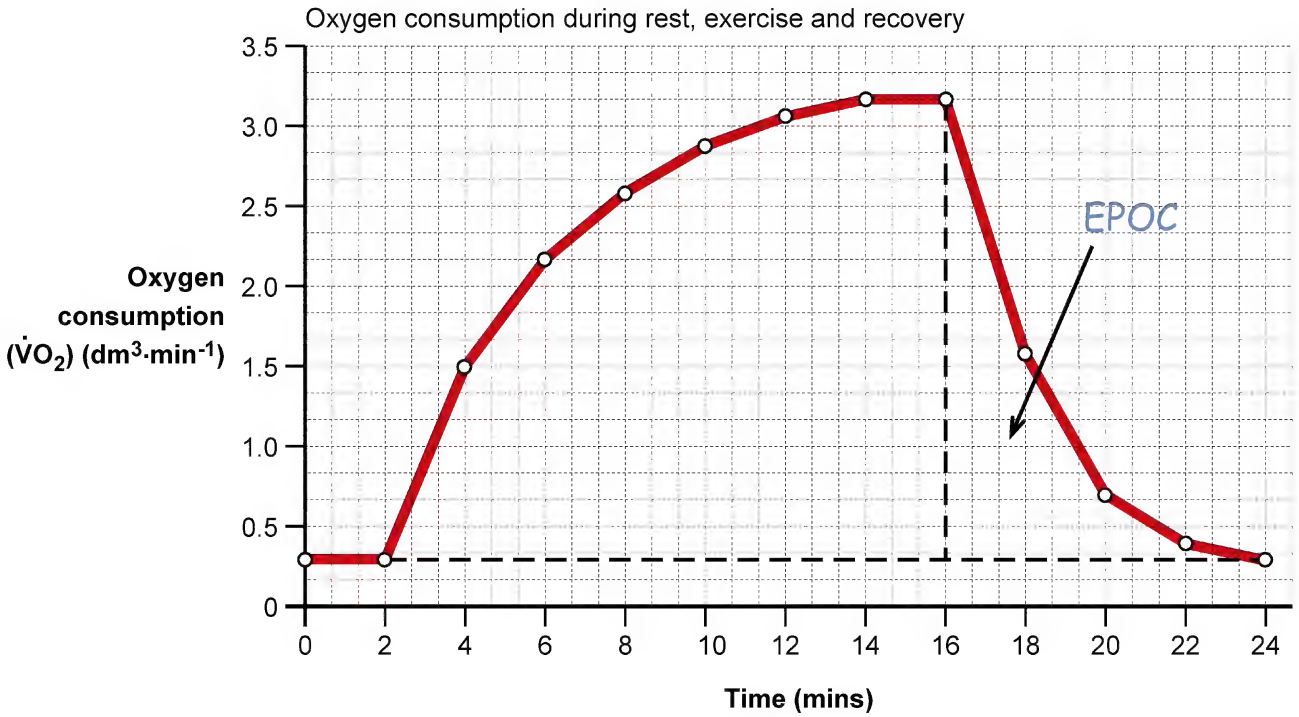
a What are the major sources of energy used when we exercise at an intense level?

When we exercise, we use two primary sources of energy, the phosphagens (ATP and phosphocreatine) and glycogen.

During recovery, our energy demand is much lower than whilst we are exercising, but our oxygen demand is still quite high for a period of time, the length of which depends on the intensity of exercise.

This higher than resting level of oxygen consumption used to be called our oxygen debt, but is now more properly called our **E.P.O.C.** (Excess Post-exercise Oxygen Consumption).

b Label EPOC on the graph you drew for task 1.



Task 2 *continued*

Because we use two different energy sources for exercise (PC and glycogen) there are two components to EPOC, a **fast** component and a **slow** component.

The fast component is concerned with getting the PC energy system back to normal, thus we talk about **phosphagen or phosphocreatine restoration**, whilst at the same time re-saturating myoglobin with oxygen. This component is replaced very quickly if exercise is highly aerobic.

During strenuous exercise, we produce lactate. Returning the body systems to normal following strenuous exercise may take several hours. This is the slow component. This slower phase of the recovery process is also used for other processes apart from removing lactate, such as the extra oxygen needed to supply the breathing and heart muscles.

c Distinguish between the fast and slow components of EPOC.

The fast component is concerned with PC restoration and resaturation of myoglobin; the slow component is concerned with the removal of lactate and using oxygen for metabolic processes.

Lactate is mainly removed from the blood by its conversion back into pyruvate and subsequent oxidation to CO_2 and water, which produces ATP. This occurs in muscles that have sufficient oxygen, or can happen in other organs where oxygen is available, such as the liver.

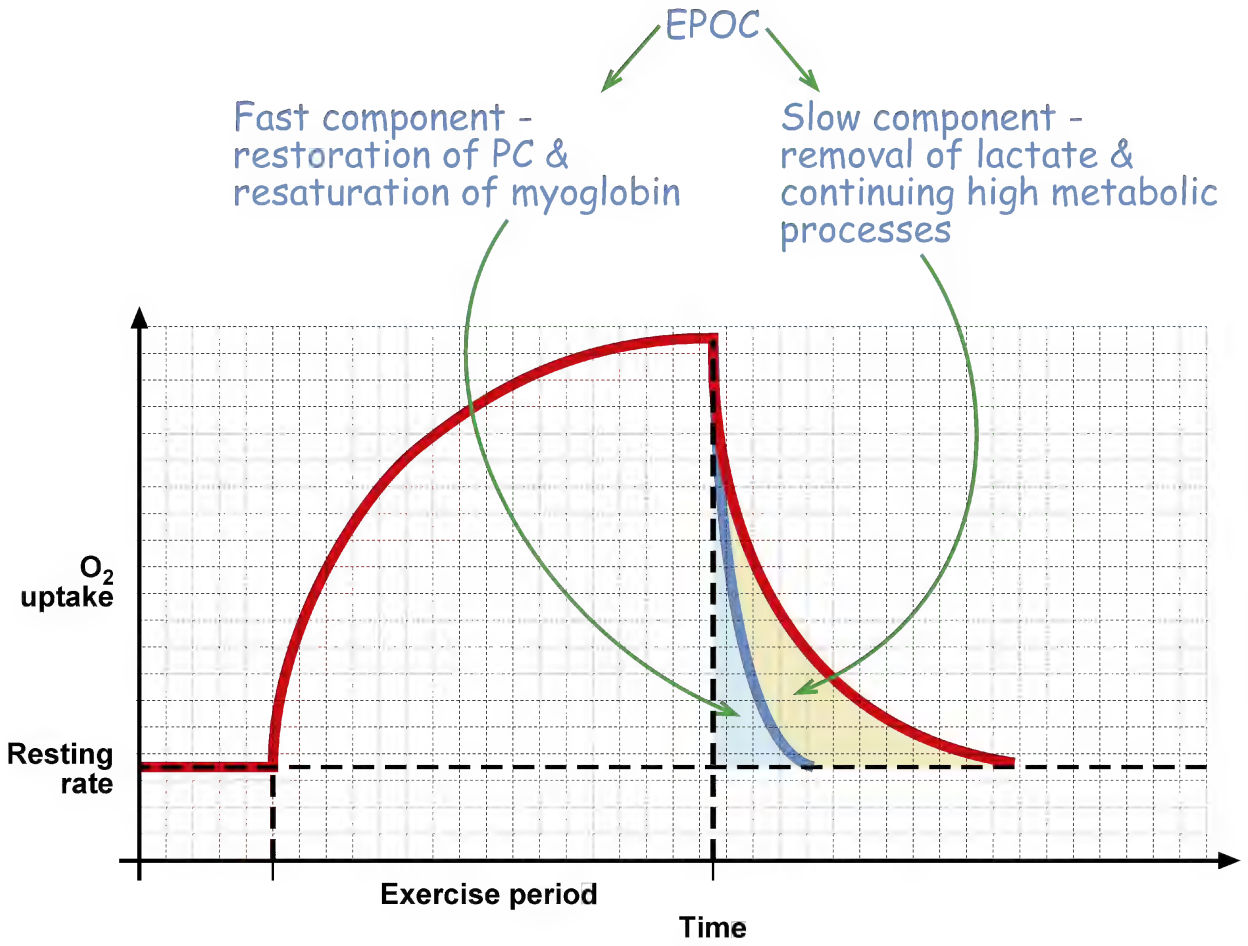
Some lactate is converted to pyruvate and glucose in the liver for later use in respiration, and a negligible amount is excreted in urine and sweat.

d How is lactate removed from the blood during the slow component of EPOC?

Conversion to pyruvate (and subsequent oxidation) and glucose; some excreted in urine and sweat.

Task 3

a Draw a graph that shows the fast and slow components of EPOC, together with their specific roles.


EPOC
Fast component - restoration of PC & resaturation of myoglobin
Slow component - removal of lactate & continuing high metabolic processes
O_2 uptake
Resting rate
Exercise period
Time

Teaching Resource

Part 4 Performance Criteria

B Maximum Oxygen Consumption

Feltham Press

General Considerations and Objectives

1. To allow students to understand and use appropriate terminology to define and describe maximum oxygen consumption
2. To enable students to appreciate the role of this term as a means of predicting aerobic performance

Tasks

In this study pack you will find a range of tasks that require the students to develop their knowledge and understanding of the term maximum oxygen consumption

Students will need to

1. Understand the terminology and units used to describe maximum oxygen consumption
2. Be able to apply these principles to observed performance

The concept of maximal oxygen consumption is quite difficult to understand for many, as it involves a level of energy expenditure that is often outside their experience. The role of the teacher here is to simplify the concept so that students have sufficient understanding to explain the use of maximum oxygen consumption during specific performances.

All the tasks involved require the students to work either from the tasks as free-standing units, or to use the tasks as additional reinforcement and/or revision to class-delivered lessons.

Assessment of this work could simply be as answers to the posed questions, or assessed as part of a group's work, or through class discussion.

Task 1

Read through the following material, answering the questions posed in the spaces provided.

When we exercise, we take in oxygen to supply muscles so that they can release energy aerobically. If the level of exercise intensity increases, so does the level of oxygen uptake. This relationship continues until, during extreme exercise, we reach a level of **maximum oxygen consumption**.

Maximum oxygen consumption is therefore defined as:

"**the greatest amount of oxygen uptake that an individual can achieve during exercise**."

a Explain why oxygen consumption increases when we exercise

When we exercise we use more energy; energy release requires the use of oxygen.

Task 1 *continued*

$\dot{V}O_2$ max is usually regarded as an accurate indication of the athlete's aerobic ability or stamina (cardio-respiratory endurance), since it directly estimates how much oxygen the athlete has available for energy release. $\dot{V}O_2$ max varies with training and fitness. The fitter you are in terms of aerobic fitness the higher your $\dot{V}O_2$ max.

When you exercise you tend to work at a level of oxygen consumption that is some percentage of your $\dot{V}O_2$ max; the value being dependent on your level of fitness and the intensity of the exercise.

Linked to this is the concept of lactate threshold or Onset of Blood Lactate Accumulation (OBLA). The harder you exercise, the more likely you are to generate lactate as a waste product of anaerobic metabolism within your blood. When this level reaches 2-4 millimoles of lactate per litre of blood above normal resting levels, the term **lactate threshold** is used.

b Why can you not exercise at your $\dot{V}O_2$ max for more than a few seconds?

Exercising at $\dot{V}O_2$ max involves maximal intensity, which means that lactate builds up in the blood, causing fatigue.

c How is lactate threshold related to $\dot{V}O_2$ max.

Lactate must begin to be produced before $\dot{V}O_2$ max is finally reached, hence lactate threshold must be some proportion/percentage of $\dot{V}O_2$ max.

Task 1 *continued*

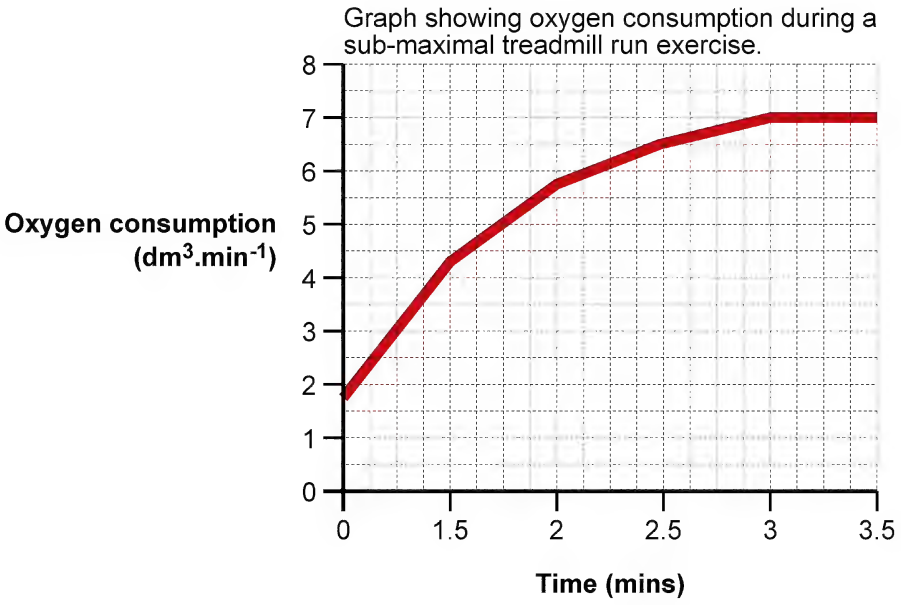
Athletes must therefore balance the intensity of their exercise so as not to accumulate too much lactate within their blood, whilst at the same time work at a level close to their $\dot{V}O_2$ max. The fitter the athlete, the higher their $\dot{V}O_2$ max, and the closer to their $\dot{V}O_2$ max that their lactate threshold occurs.

Elite performers will be able to exercise at a level that is 90% of their $\dot{V}O_2$ max. Less fit individuals may have to be satisfied with a workload nearer 60-70% of their $\dot{V}O_2$ max

Oxygen consumption can be expressed in a variety of ways, including: decimetres cubed per minute (dm^3/min); centimetres cubed per minute (cm^3/min); or, centimetres per kilogram of body weight per minute (cm^3/kg/min). The latter, which takes into account the weight of the subject, is the most widely accepted.

You consume oxygen whilst at rest, in order to supply the body's need for energy to maintain life. This resting oxygen consumption is approximately 3.5 cm^3/kg/min. Once you begin to perform exercise, oxygen consumption rises. If the level of exercise is constant and sub-maximal, the oxygen consumption reaches a 'steady state', where it levels out.

The following graph shows how oxygen consumption gradually increases in the first few minutes of execise until it reaches a 'steady state' at a particular level of exercise.



d What is the 'steady state' oxygen consumption as shown by the graph.

7 dm^3

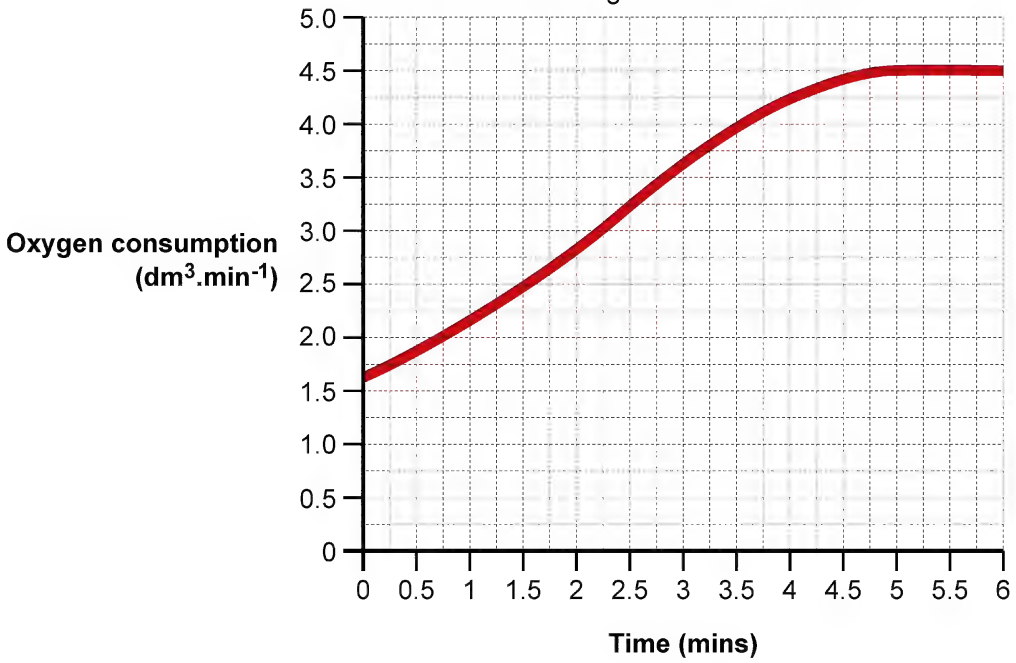
Task 1 *continued*

In practice, oxygen consumption is measured by subtracting the volume of oxygen expired during a period of time, from the volume of oxygen inspired during that same time period.

During a treadmill run, or a ergometer ride, or any static aerobic activity, where the workload is able to be increased every three minutes or so, oxygen consumption will rise during each stage of the test, until the runner is unable to continue due to exhaustion.

At this point in time, the runner is said to have reached his or her work or **aerobic capacity**. The amount of oxygen being consumed in these final few seconds of exercise is then measured, to give a value for $\dot{V}O_2$ max.

Graph showing oxygen consumption reaching a plateau (maximum oxygen consumption), during a treadmill run exercise of increasing workload.



Measurement of $\dot{V}O_2$ max by such methods are called **direct methods** of measurement.

Task 1 *continued*

e Suggest an advantage and disadvantages of using direct methods of measuring oxygen consumption.

advantage – accuracy; disadvantages – cost of equipment, time involved (one subject at a time), reliance on motivation, health risk because of maximal exertion

f What will be the principle source of fuel for regenerating ATP at the high work intensities reached during this type of test?

Glycogen

g Comment on the use of energy sources during a $\dot{V}O_2$ max test.

All three sources of energy utilisation are operating at or near maximum, output. The PC/ATP system becomes "exhausted" within the first few seconds of heavy work. The lactate anaerobic system will function at near maximal capacity, and the rate of glycogen use will also be maximal. Fat usage will not be at maximum near the end of the test because of the limited oxygen supply

Task 1 *continued*

Training has an effect on $\dot{V}O_2$ max. The extent of the effect largely depends on the intensity of the training workload, the length of time that the training programme is undertaken and the genetic disposition of the performer to become adapted to training.

The effects of training are to increase $\dot{V}O_2$ max by between 5 and 20%. The main causes of these increases are changes to the blood, heart and muscles.

The volume of the circulating blood and the levels of haemoglobin increase within days of the commencement of training. This will cause an increase in the stroke volume of the heart because of an increased venous return (Starling's Law of the heart).

h Explain why an increase in haemoglobin content will increase $\dot{V}O_2$ max.

Haemoglobin transports oxygen, more haemoglobin would supply more oxygen to exercising muscles

There is a longer-term effect on the heart. A training programme that lasts months or even years will result in **cardiac hypertrophy**.

i What do you understand by the term cardiac hypertrophy?

Increase in the size of the heart due to increased volume of the ventricles

This hypertrophy also increases the stroke volume of the heart, and as resting cardiac output would remain relatively constant, this results in a reduction in the resting heart rate (**bradycardia**).

j Explain why training causes a decrease in the resting heart rate.

Training causes an increase in stroke volume, and as cardiac output (Q) = HR x SV, and Q remains the same, the heart rate must decrease

Training also causes biochemical and structural changes to skeletal muscles, each of which enables the muscle fibres to use oxygen to produce energy at a more efficient rate. Thus training causes an increase in the size and numbers of mitochondria within muscle fibres, together with a corresponding increase in oxidative enzyme concentrations.

k What is the function of mitochondria and oxidative enzymes?

Mitochondria are the site of aerobic energy production; oxidative enzymes are the chemicals that control the breakdown of glycogen and fats to release energy aerobically.

Task 1 *continued*

Training also causes an increase in myoglobin content of muscle fibres, and an increase in capilliarisation of muscle fibres

l Explain how increase myoglobin content and capilliarisation of muscle fibres increases $\dot{V}O_2$ max.

Myoglobin acts as an oxygen store/supply in muscle fibres; any increase in myoglobin content will make more oxygen available to mitochondria; capillaries supply oxygen to muscle fibres; an increase in oxygen supply would increase $\dot{V}O_2$ max.

Training also causes a decrease in lactate accumulation in muscles, which is usually described as an increase in **lactate tolerance**.

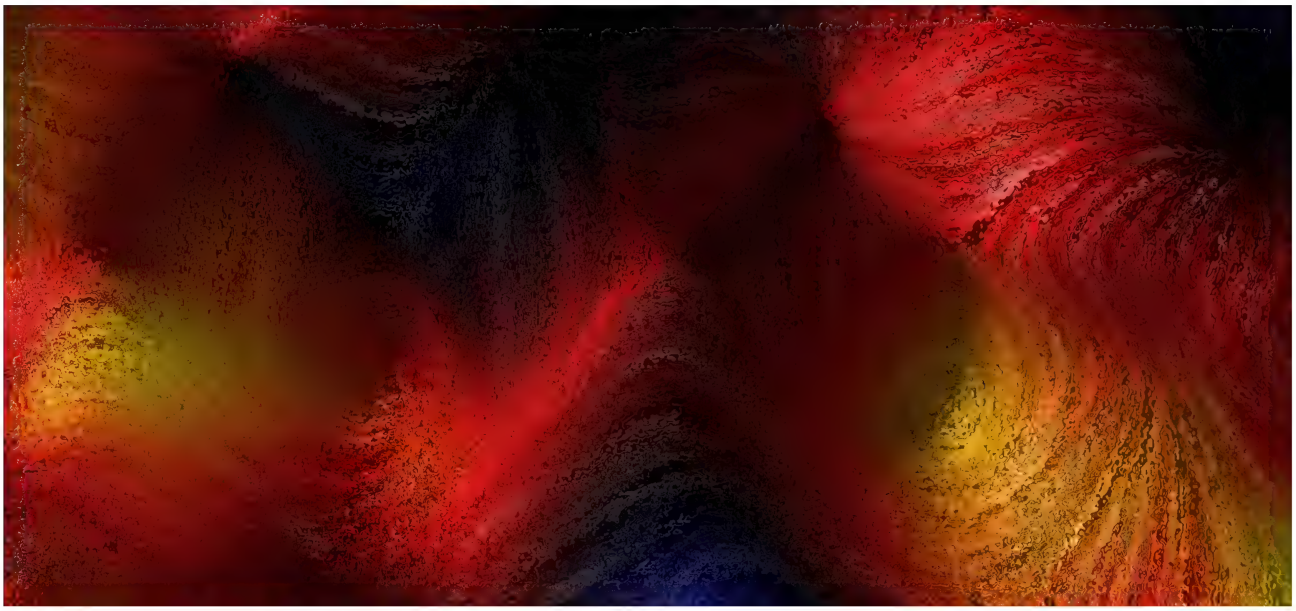
m Suggest why there should be a decrease in lactate accumulation as a response to training.

Because of the increase in mitochondria, there would be more glycolytic energy production and correspondingly less lactate production; there would be an increased use of fats as a energy substrate; there would be increased use of lactate as a metabolic substrate.

Teaching Resource

Part 4 Performance Criteria

C Lactate Threshold



Feltham Press

General Considerations and Objectives

1. To allow students to understand and use appropriate terminology to define and describe the parameters involved with the lactate threshold
2. To enable students to appreciate the role of this term as a means of predicting exercise intensity and performance

Tasks

In this study pack you will find a range of tasks that require the students to develop their knowledge and understanding of the term lactate threshold

They will need to

1. Understand the terminology and inferences made concerning lactate threshold
2. Be able to apply these principles to observed performance

The concept of lactate threshold is relatively simple to understand for many, as it involves a level of energy expenditure that is within their experience. The role of the teacher here is to simplify the concept so that students have sufficient understanding to explain the use of lactate threshold during specific performances.

All the tasks involved require the students to work either from the tasks as free-standing units, or to use the tasks as additional reinforcement and/or revision to class-delivered lessons.

Assessment of this work could simply be as answers to the posed questions, or assessed as part of a group's work, or through class discussion.

Your centre may also have suitable handouts, posters or videos that will help. The benefit of having the teacher as the ultimate resource cannot be over-emphasised.

Task 1

During heavy exercise, the increasing levels of acidity in the blood cause an increase in ventilation rate.

a Suggest two causes of this increasing acidity.

Increase levels of the acidic gas carbon dioxide, and increasing levels of lactate.

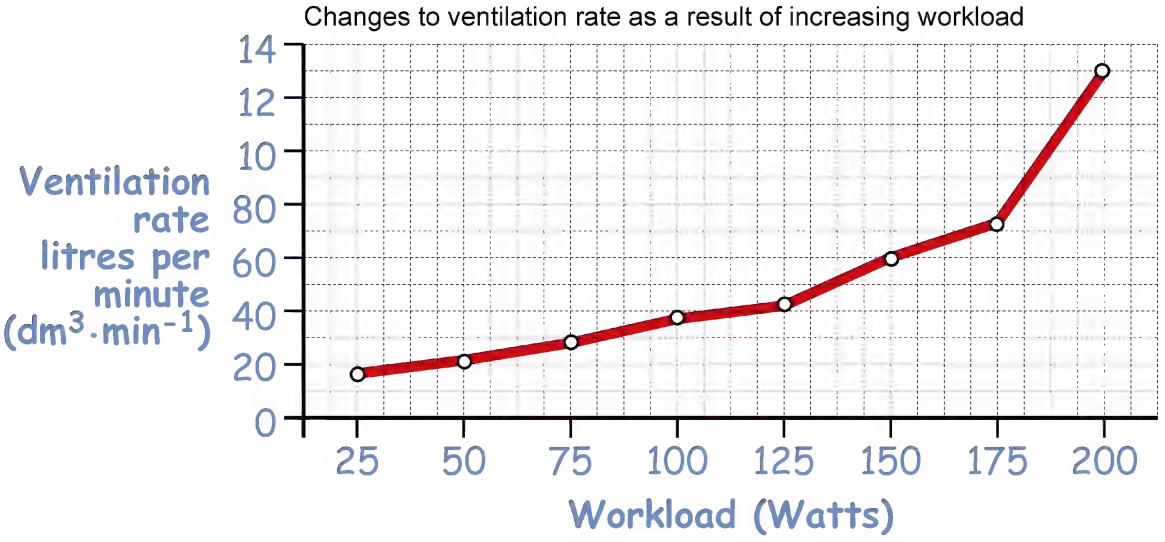
But the relationship between workload and ventilation rate is not linear, as might be expected.

Values as below have been found:

Ventilation Rate	Workload (watts)
16 litres per min	25
20 litres per min	50
28 litres per min	75
36 litres per min	100
42 litres per min	125
58 litres per min	150
72 litres per min	175
130 litres per min	200

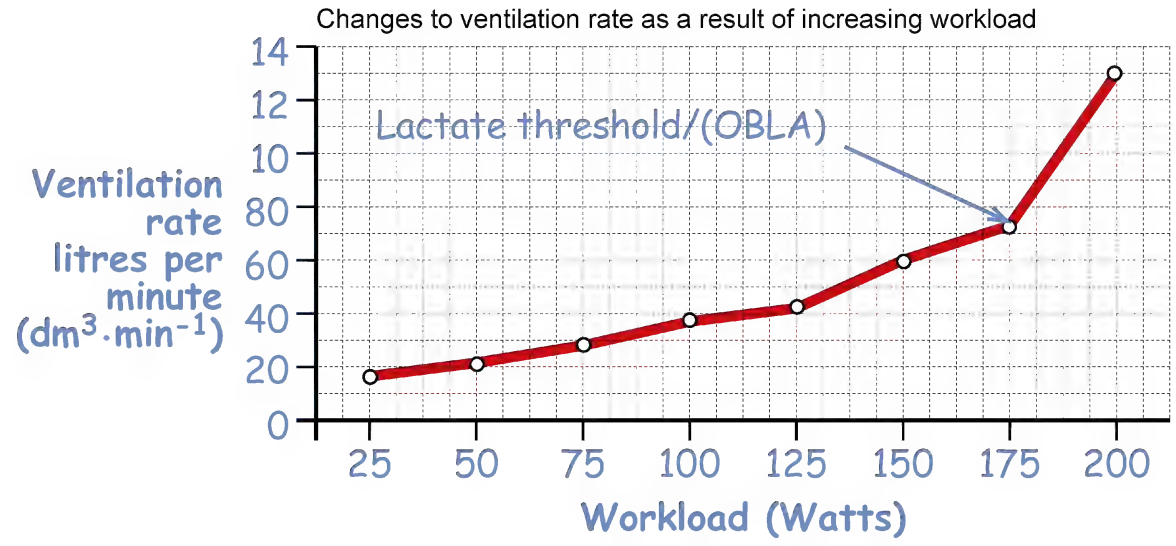
Task 1 *continued*

b Draw a graph of the above values, plotting workload (x-axis) against ventilation rate (y-axis).



As can be seen, the linear relationship between ventilation rate and workload changes at about 175 litres per minute. This upward breaking point is called the **'ventilatory break point'** which is assumed to equate to the **lactate threshold** or **OBLA** (onset of blood lactate accumulation).

c Label OBLA or lactate threshold on your graph.



Task 1 *continued*

d Describe how and why muscles cells produce lactate.

During intense exercise, mitochondria are unable to supply sufficient energy through aerobic processes, this leads to an excess of pyruvate which is converted to lactate, which in turn accumulates initially in the muscle, and then eventually in the blood

e How is this increase in blood acidity detected and relayed to the brain?

Increasing blood acidity is detected by the chemoreceptors in the carotid bodies in the arteries in the neck which send impulses to the respiratory centre to increase breathing rate

Once produced, some of the lactate is converted into glycogen or glucose by the liver, but the majority is converted back into pyruvate in skeletal muscle when sufficient oxygen is present and used as a fuel source.

In practice, lactate is always present in blood and additional amounts are produced during the mildest of exercise, because anaerobic energy production invariably occurs at the start of any exercise. But this lactate is generally removed as quickly as it is produced.

Task 1 *continued*

f What is the name given to the period of time during recovery when lactate is being removed from the circulation?

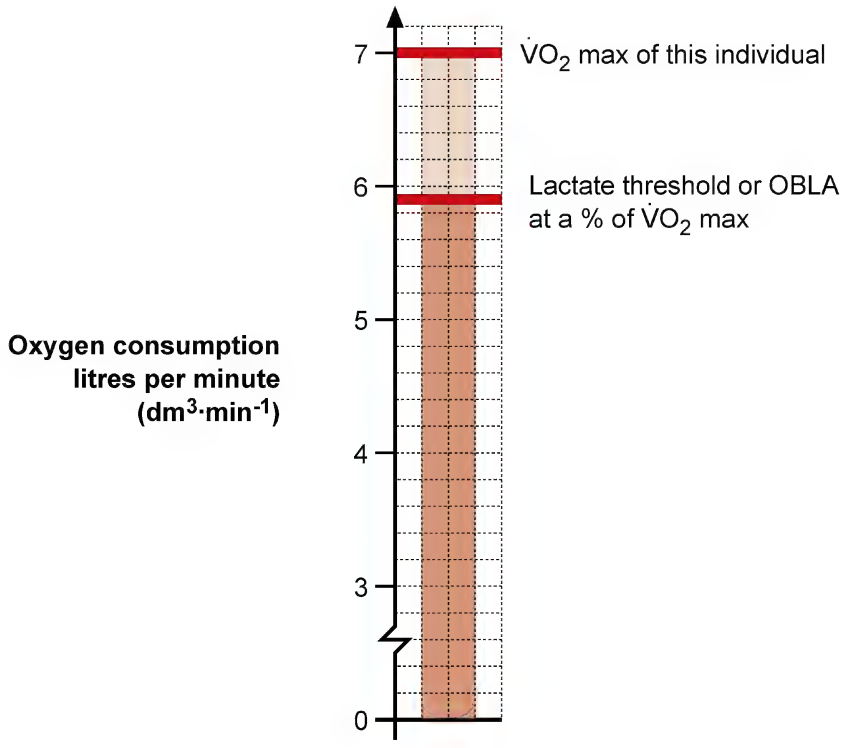
EPOC – slow component

When lactate production exceeds the rate at which it can be removed, then it begins to accumulate, firstly in the muscles where it is being produced and then in the blood as it diffuses out from the muscle.

It is generally accepted that an increase in the resting levels of lactate of 2-4 millimole of lactate per litre (dm^3) of blood is the equivalent to the lactate threshold, because lactate is accumulating in the blood, and this level has also been called the Onset of Blood Lactate Accumulation (OBLA). However, due to the continuous nature of the increase, some argue against the use of terms such as threshold.

Lactate threshold or OBLA occurs at a certain percentage of the $\dot{V}O_2$ max, depending on the level of fitness of the subject.

The following diagram shows this principle:

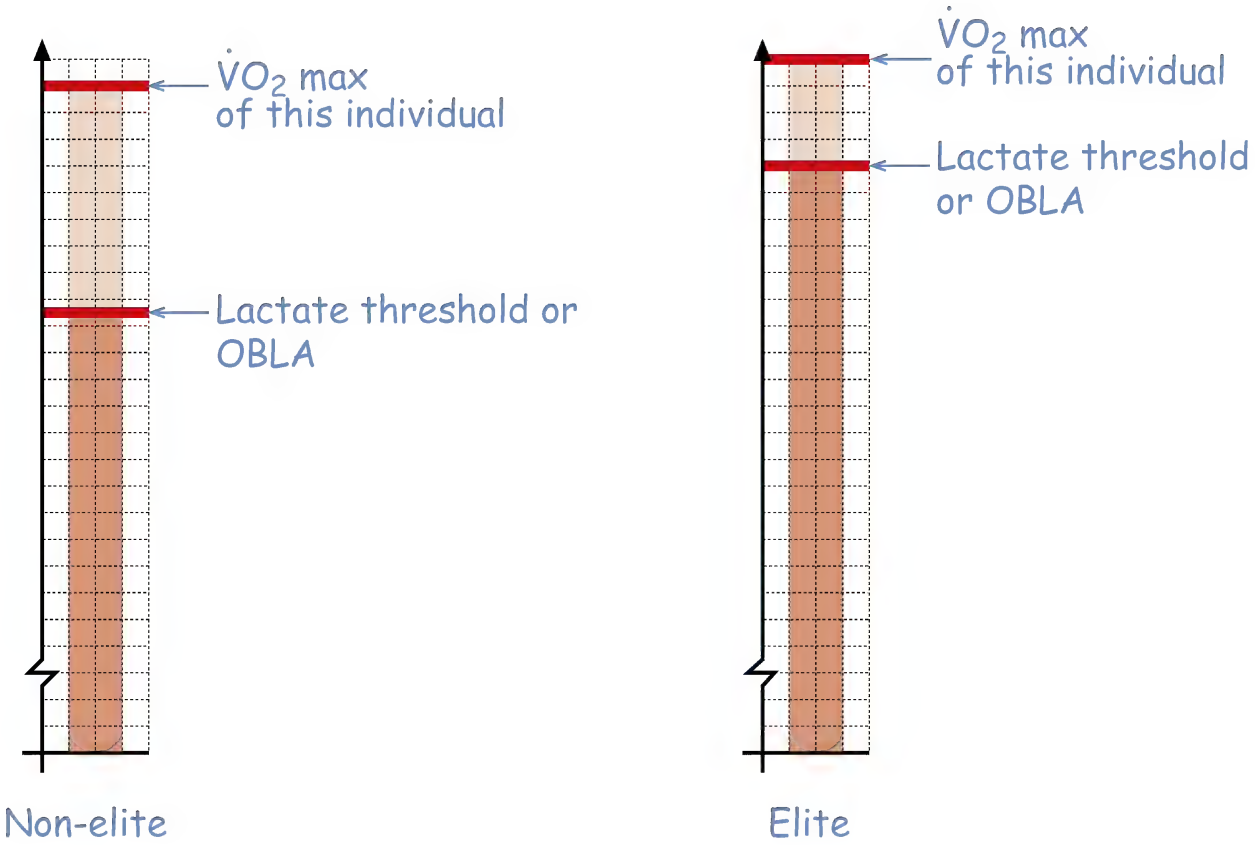


Task 1 *continued*

As fitness increases so does the lactate threshold. Non-elite performers may have a lactate threshold that is 60% of their $\dot{V}O_2$ max, whereas elite performers may have a lactate threshold that is 90% of their $\dot{V}O_2$ max.

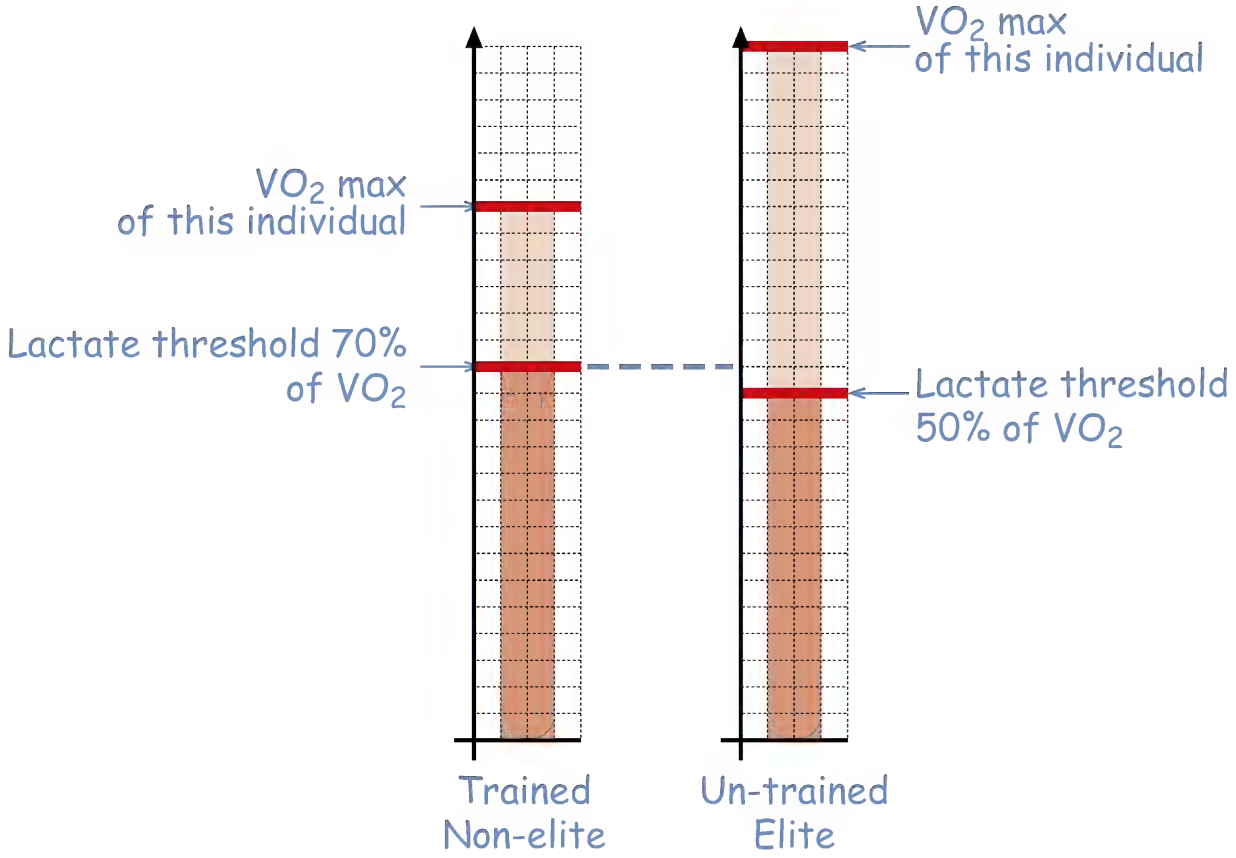
Training has a limited (5-20%) effect on $\dot{V}O_2$ max, the big difference in performance comes from the improving lactate threshold. When we exercise we tend to work at or just below our lactate threshold. In other words at a level where fatigue (caused by lactate) is not going to cause our performance to deteriorate. The fitter we are the higher our lactate threshold and hence the harder we can work.

g Using the diagram shown previously as a guide, draw another diagram to show the difference between a non-elite and an elite performer in terms of $\dot{V}O_2$ max and lactate threshold.



Task 1 *continued*

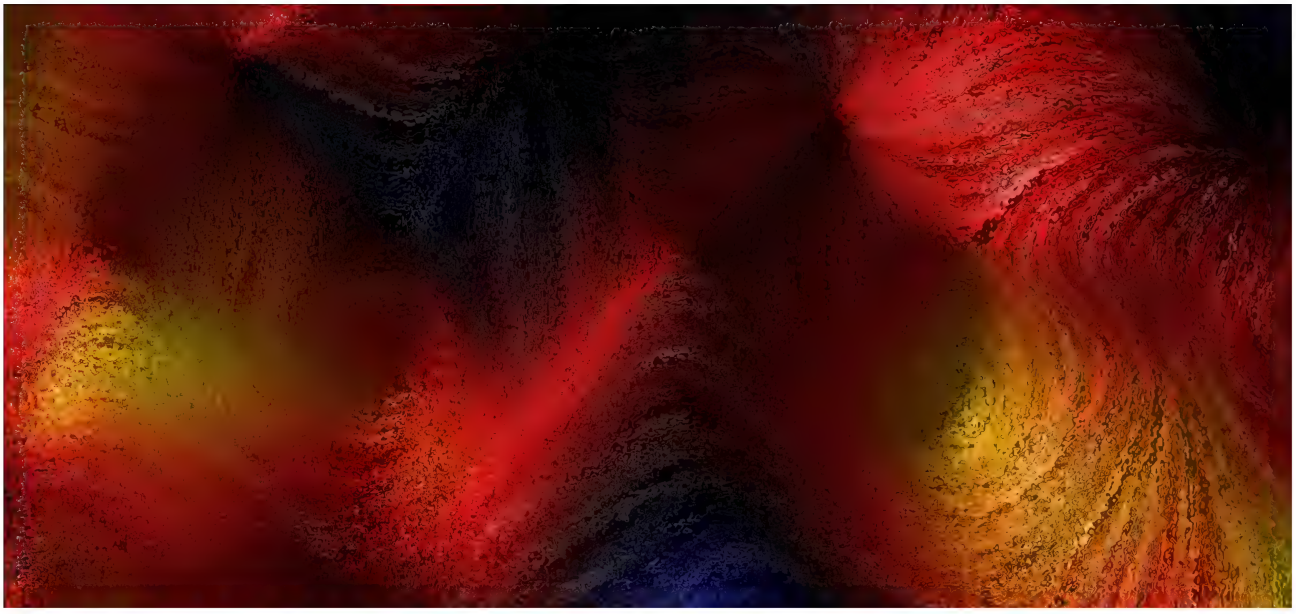
h Similarly show how a trained non-elite performer could perform better than a non-trained elite performer..



Teaching Resource

Part 5 Motor Units and Control

A Types of muscle fibre



Feltham Press

General Considerations and Objectives

1. To allow students to understand and use appropriate terminology to describe the different type of muscle fibre
2. To enable students to appreciate the essential role of different muscle fibres during muscle contraction
3. To enable students to understand the limited use of knowledge of muscle fibre types as predictors of performance

Tasks

In this study pack you will find a range of tasks that require the students to develop their knowledge of the terms and relationships involved in muscle fibres and motor units.

Students will need to

1. Understand and use the essential terminology used to describe muscle fibres
2. Appreciate the role of the different muscle fibre types during differing activities
3. Be able to apply these principles to observed performance

The concepts of different fibre-types should be relatively straightforward for the student to understand, as they form a natural extension to work previously completed on energy systems. The role of the teacher here is to explain the practicalities involved so that students have sufficient understanding to be able explain the role of muscle fibres during specific performances.

All the tasks involved require the students to work either from the tasks as free-standing units, or to use the tasks as additional reinforcement and/or revision to class-delivered lessons.

Assessment of this work could simply be as answers to the posed questions, or assessed as part of a group's work, or through class discussion.

There is no need for detailed knowledge of the biochemistry of energy systems to be delivered or understood.

Task 1

Read through the following materials, answering questions in the spaces provided.

The movements that occur during sporting performance are due to the action of skeletal muscles contracting to cause the bones that make up our joints to move. Skeletal muscles consist of bundles of **fibres** that may be several centimetres long, and up to 2 cms across. They appear to have light and dark stripes when viewed under a microscope, and therefore this type of muscle is sometimes called striped or **striated** muscle.

Only rarely do individual muscle fibres run the whole length of a muscle; more usually they are connected to other fibres by connective tissue, which is continuous with the tissue that forms tendons.

Different types of muscle fibre exist. There are two major types of muscle fibre within a single skeletal muscle: **Slow-twitch** (ST) and **Fast-twitch** (FT). They are named according to how quickly they can reach peak tension (contract).

a What is the essential difference between fast and slow-twitch muscle fibres?

speed of contraction

Slow-twitch fibres are adapted for slow rhythmical contractions, although they can still contract quickly enough for all essential sporting activities; they tend to be smaller in cross section and produce less overall force than fast-twitch fibres.

The slow-twitch fibres are more energy efficient, and are therefore well adapted for prolonged exercise, where the supply of energy might become a factor that limits performance. By comparison, fast-twitch fibres are easily fatigued.

b Complete the following table to show the differences between fast and slow-twitch muscle fibres.

	fast-twitch	**slow-twitch**
type of contractions	fast, non-rhythmical	slow, rhythmical
cross-section	*larger*	*smaller*
amount of force produced	*more*	*less*
energy efficiency	*less*	*more*
adapted for	*short duration exercise*	*long duration exercise*
resistance to fatigue	*non-resistance*	*resistance*

Task 1 *continued*

c What would be the predominant fibre being used in a marathon race? Explain your answer.

slow-twitch – slow, rhythmical contractions; more energy efficient; long duration exercise; not easily fatigued

Most muscles contain different proportions of slow-twitch and fast-twitch fibres:

Approximate Percentages of Slow-twitch (Type I) Fibres in Muscles from Sedentary Human Males, 20-35 Years of Age

Muscle	% Slow Twitch
Soleus	87
Tibialis Anterior	73
Deltoid	52
Gastrocnemius	44
Biceps Brachii	43
Triceps Brachii	32

d Look at the above table, can you suggest a trend in the figures?

More slow-twitch muscle fibres in leg muscles; less in arm muscles

Task 1 *continued*

In general, slow-twitch fibres have a high level of endurance; they are suited to aerobic exercise. They produce their ATP primarily from aerobic energy pathways (see notes).

Because of this they are recruited most often during low-intensity endurance events.

e Give three examples of exercises where slow-twitch fibres would be the type being predominantly used:

1 long distance/duration running

2 long distance/duration rowing

3 long distance/duration cycling

Fast-twitch muscle fibres have relatively poor aerobic endurance. They are better suited to **anaerobic** activity, as they produce their ATP primarily from anaerobic energy pathways.

f What do you understand by the term 'anaerobic energy pathways'?

Energy production in the absence of oxygen; involves breakdown of PC and/or glycogen to release energy for ATP resynthesis

Task 1 *continued*

It would appear from research that the percentage of fibre types that any one muscle and/or any one person has is due to heredity. You are born with varying distributions, although the average would appear to be 50% slow-twitch and 50% fast-twitch.

You cannot change these percentages through training.

It would also appear that a higher proportion of fast-twitch fibres would be an advantage in events requiring anaerobic energy, such as sprinting, throwing, jumping and research has repeatedly shown that this is the case.

In the same way, it could be expected that on average, marathon runners have a greater proportion of slow-twitch fibres than the rest of the population. However, mere possession of the correct proportions of fast-twitch or slow-twitch muscle fibres, is no guarantee of sporting success in a particular activity.

The same research also shows that there is a range of slow-twitch:fast-twitch ratio's in sprinters and marathon runners, to the extent that some sprinters have lower percentages of FT fibres than marathon runners, and vice-versa.

g What does the following table suggest about the proportions of muscle fibre types and athletic ability?

	Range of % Slow-twitch fibres	**Average % Slow-twitch fibres**
Male marathon runners	50-95	85
Male 800 metre runners	50-80	55
Male sprinters	20-55	35

Although marathon runners have on average a greater proportion of slow-twitch fibres than sprinters, the ranges do overlap – there are marathon runners who have less slow twitch fibres (50%) than some sprinters (55%).

Task 1 *continued*

At least two types of fast-twitch fibre have been identified; a **fast-twitch type a** (FTa) or fast oxidative glycolytic [FOG], and a **fast-twitch type b** (FTb) fast-twitch glycolytic [FG].

FTa (FOG) have a degree of oxidative (aerobic) capacity. Thus, FTa fibres appear to be used mainly during short, high-intensity endurance events such as a 1-mile run, or 400m swim.

Although the significance of FTb (FG) fibres are not fully understood, they appear to be the predominant fibre that is recruited in highly explosive events, such as 100m sprints, or 50m swims.

h Using specific examples, explain how different muscle fibres may be used during a game such as basketball.

Slow rhythmical muscle contractions when moving into position/recovering would use predominantly slow-twitch muscle fibres; high intensity runs from one end of the court to the other would use FOG muscle fibres; explosive actions such as rebounding would predominantly use FG muscle fibres

i Can you see a link between muscle fibre types and energy systems?

slow twitch fibres use mainly aerobic energy systems; FOG fibres use mainly lactate anaerobic system; FG fibres use mainly ATP PC system

Task 1 *continued*

j In what ways does the following table suggest that slow-twitch muscle fibres are adapted for aerobic/endurance–type exercise?:

Classification of Muscle Fibre Types			
Characteristic	**ST**	**FTa (FOG)**	**FTb (FG)**
Oxidative capacity (aerobic energy)	High	Moderately high	Low
Glycolytic capacity (anaerobic energy)	Low	High	Highest
Contractile speed	Slow	Fast	Fast
Fatigue resistance	High	Moderate	Low
Mitochondria	Many	Many	Few
Capillaries	Many	Moderate	Few
Motor unit strength	Low	High	High

High oxidative capacity;

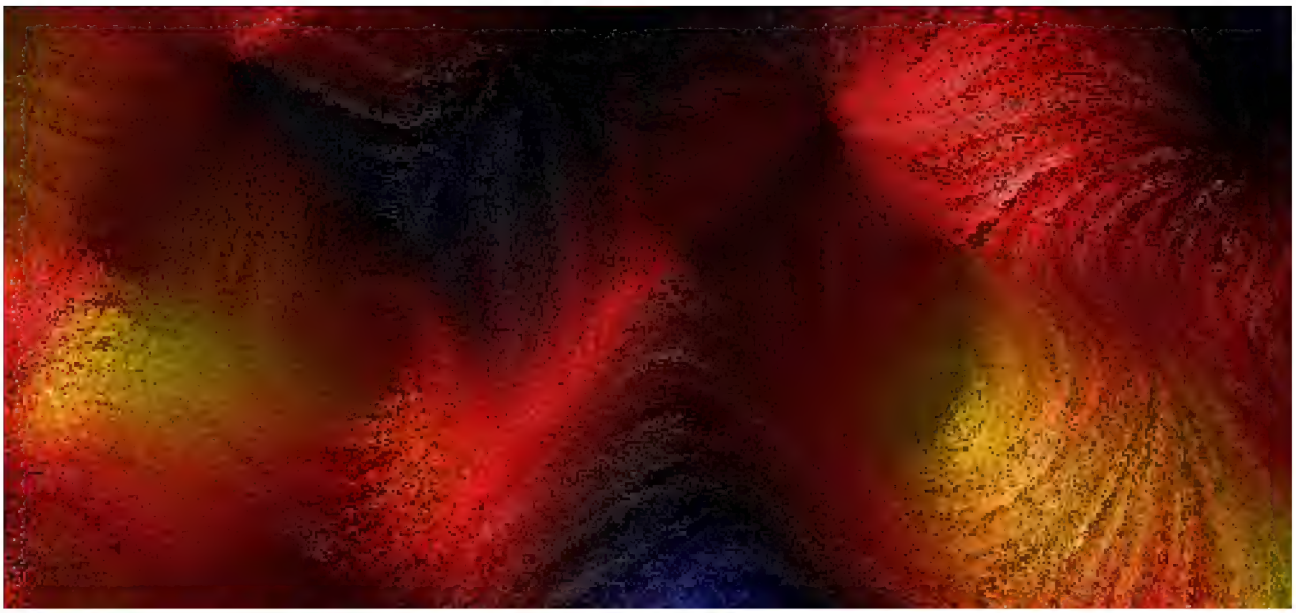
low anaerobic capacity; high fatigue resistance;

many mitochondria; many capillaries;

Teaching Resource

Part 5 Motor Units and Control

B Motor Units



.

Feltham Press

General Considerations and Objectives

1. To allow students to understand and use appropriate terminology to describe motor units and their role in control of strength
2. To enable students to understand the ways in which strength may be controlled

.

Tasks

In this study pack you will find a range of tasks that require students to develop their knowledge of the terms and relationships involved in control of strength and motor units.

Students will need to

1. Understand and use the essential terminology used to describe motor control through motor units
2. Appreciate the role of unit types during differing activities
3. Be able to apply these principles to observed performance

The concepts of motor units are relatively straightforward for the student to understand, but their role in control of strength may be a more problematic concept for them. The role of the teacher here is to explain the mechanisms involved so that students have sufficient understanding to be able to explain how motor units function during specific performances.

All the tasks involved require the students to work either from the tasks as free-standing units, or to use the tasks as additional reinforcement and/or revision to class-delivered lessons.

Assessment of this work could simply be as answers to the posed questions, or assessed as part of a group's work, or through class discussion.

The benefit of having the teacher as the ultimate resource cannot be over-emphasised.

Task 1

Read through the following materials, answering questions in the spaces provided.

Muscle fibres are activated by nerve impulses. A single motor nerve fibre (**motor neurone**) may supply (innervate) as few as 15 muscle fibres, or as many as 2000.

A motor neurone and the muscle fibres it innervates are called a **motor unit**.

All fibres within a motor unit are the same type, either fast-twitch or slow-twitch. In nearly all activities, it is the motor units with slow-twitch fibres that are recruited first. Only if the intensity of the exercise is very great, or the slow-twitch fibres become fatigued, are fast-twitch motor units recruited.

The motor neurone in slow-twitch motor units is smaller in cross section than that in a fast-twitch motor unit, and activates 10-180 slow-twitch muscle fibres, rather than the 300-800 muscle fibres activated by a fast-twitch motor neurone.

Hence, when a slow-twitch motor neurone stimulates its fibres, far fewer muscle fibres contract than when a single fast-twitch motor neurone stimulates its fibres.

Therefore fast-twitch motor units develop more force more quickly than slow-twitch motor units.

a Explain the differing roles of motor units that contain fast and slow-twitch muscle fibres.

Motor units with slow-twitch fibres recruited first; slow-twitch motor units smaller; fewer muscle fibres contracting; less force produced

It is obvious that different activities require differing amounts of strength. There are two main ways of varying the strength of contraction of a muscle, both of which require an understanding of the idea of motor units.

Task 1 *continued*

b What is the distribution of muscle fibre types in relation to motor units?

All fibres within a motor unit are the same type, either fast-twitch or slow-twitch

Motor units are of differing types, and they are located throughout the muscle, and not found close together as might be expected.

Thus each muscle consists of a variety of muscle fibre types, the relative distribution of which depends on the specific function of the muscle.

c Why in terms of performance is it more accurate to talk of fast and slow-twitch motor units, rather than fast and slow twitch muscle fibres.

Motor unit only contains one type of fibre; motor neurone dictates muscle fibre type

Each muscle fibre within a motor unit either contracts or does not contract. There is no such thing as a partial contraction. This is the **all or nothing law**. When the motor neurone of a motor unit activates the muscle fibres within that motor unit, all the fibres in that unit will contract, and they will contract maximally.

Task 1 *continued*

d What is the phenomenon called by which each muscle fibre either contracts or does not contract?

All or nothing law

When this idea is applied to a muscle as a whole, it can be seen that the force or strength produced by a muscle will depend on the size of the motor unit, and the number of units activated.

In other words, activation of a small number of motor units produces less force than a large number of units.

This variation of the number and size of the motor units recruited to regulate strength is called **spatial summation** or **multiple motor unit summation**.

e Explain the concept of spatial summation in your own words.

Spatial summation is the regulation of strength through use of differing numbers and sizes of motor units

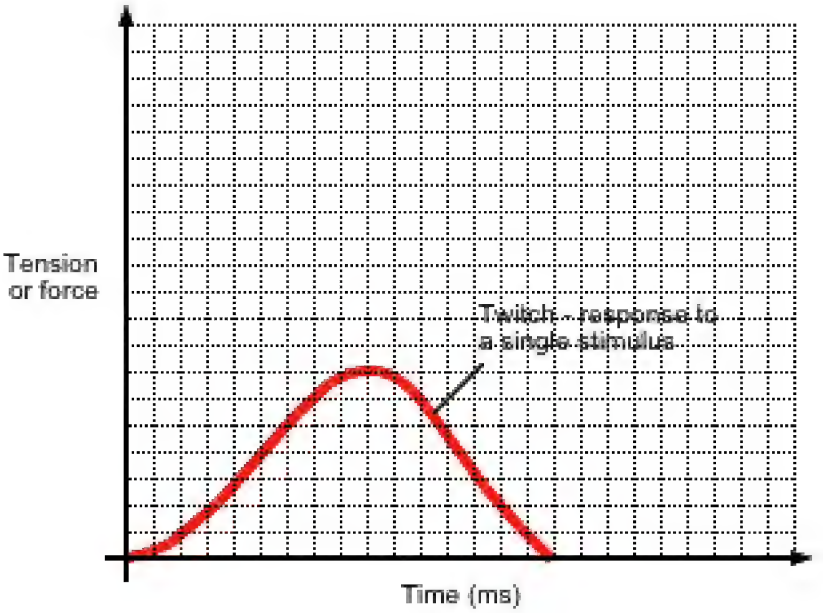
A staggered spread of activation of different motor units throughout the muscle also enables continuous contractions to be maintained without fatigue, as some motor units are contracting whilst others are relaxing (resting). This is called **asynchronous contraction**.

Another method of adjusting strength output from a specific muscle is by varying the frequency of nerve impulses reaching a motor unit.

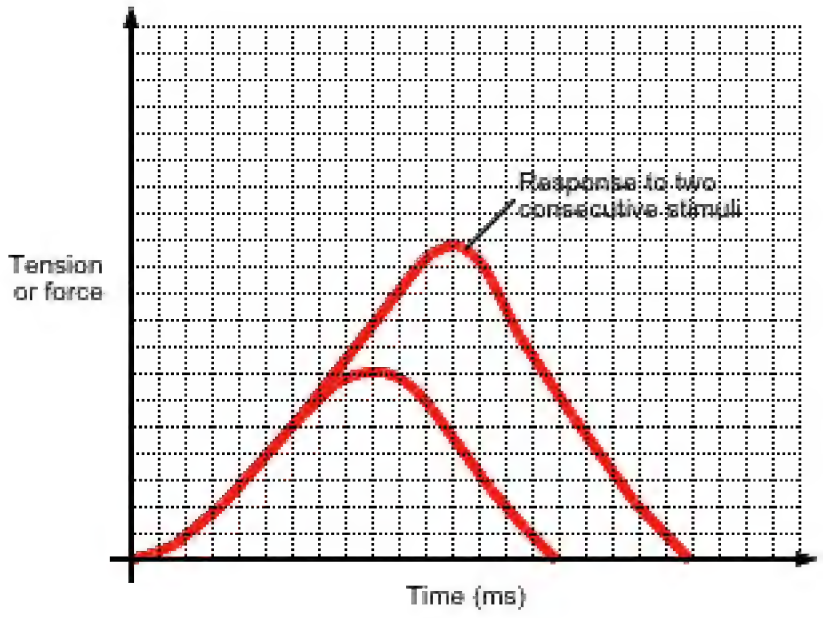
Task 1 *continued*

A single impulse from a motor neurone produces a brief period of contraction of a motor unit, followed by relaxation. This is called a **twitch**.

A recording of such a twitch is shown in the following diagram.

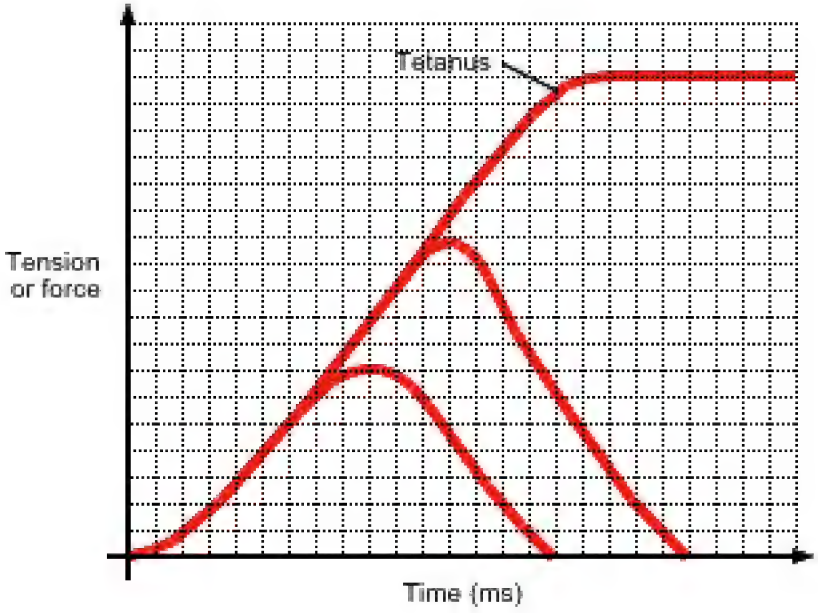


If a second nerve impulse is applied to a motor unit before it completely relaxes from the previous twitch, the tension (force) produced by the second stimulus is greater than that produced by a single twitch alone. This idea is called summation.



Task 1 *continued*

If the frequency of nerve impulses is such that a motor unit contracts before it has time to fully relax from the previous contraction, it starts the next contraction from a higher level of force output, so that each contraction produces greater force that the previous one.



This adding together of contractions or **wave summation** can, if the impulses arrive quick enough, eventually lead to a complete fusion of full strength contractions, called **tetanic contractions (tetanus)**, which can be maintained until the muscle fibres fatigue.

Thus by varying the numbers, types of motor units involved, and the frequency of their activation, the strength of contraction of a muscle can be varied to the extent that we are all familiar with.

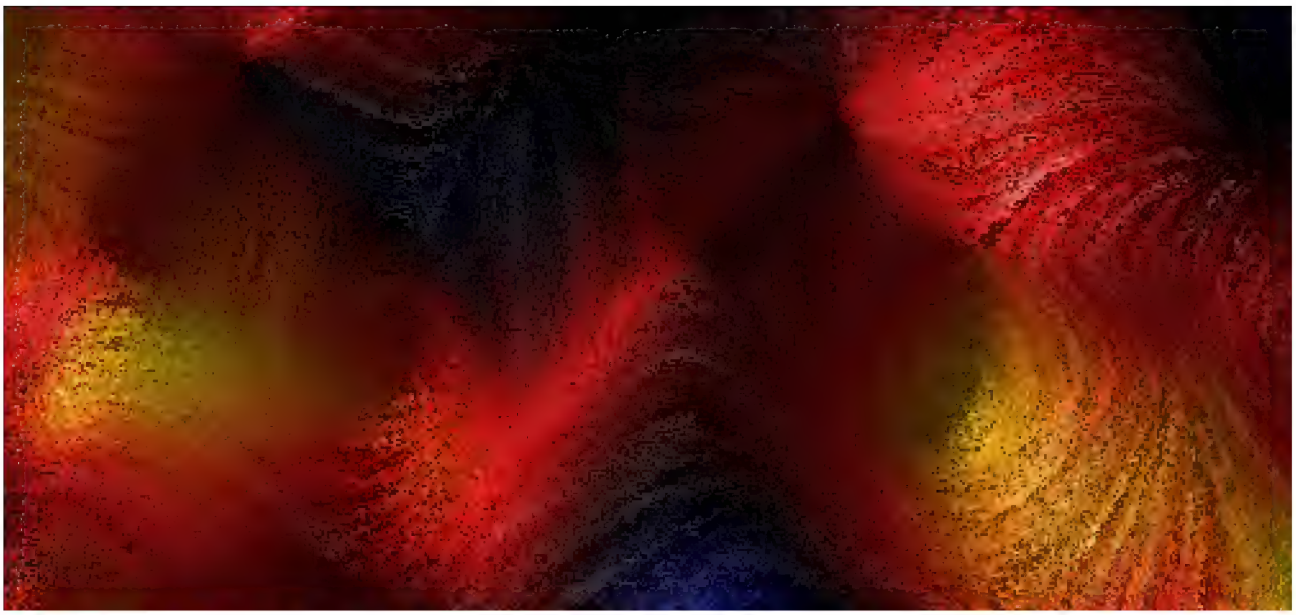
f Explain in your own words how the strength of a motor unit is increased through wave summation.

Continuous stimulation through nerve impulses from motor neurones before the motor unit has had time to fully relax causes the motor unit to increase its strength of contraction

Teaching Resource

Part 5 Motor Units and Control

C Proprioceptors and Kinesthetic Feedback



Feltham Press

General Considerations and Objectives

1. To allow students to understand and use appropriate terminology to describe muscle spindles and their role in control of muscle contraction
2. To enable students to understand the ways in which strength may be controlled

Tasks

In this study pack you will find a range of tasks that require the students to develop their knowledge of the terms and relationships involved in muscle spindles and control of strength.

Students will need to

1. Understand and use the essential terminology used to describe motor control through muscle spindles
2. Appreciate the role of muscle spindles in controlling the action of muscles
3. Be able to apply these principles to observed performance

The concepts of muscles spindles are difficult concepts for the student to understand. The role of the teacher should be to make the concept simple enough so that students have sufficient understanding to be able to explain how muscle spindles function during specific movements.

All the tasks involved require the students to work either from the tasks as free-standing units, or to use the tasks as additional reinforcement and/or revision to class-delivered lessons.

Assessment of this work could simply be as answers to the posed questions, or assessed as part of a group's work, or through class discussion.

Task 1

Produce 3 or 4 boxes of similar size and shape that are of different weights. The boxes that are used to supply reams of paper are ideal, and paper also makes a good method of altering the weight. The boxes should be identical in appearance and closed so the contents cannot be seen.

Working with a subject, ask the subject to stand in front of the class and flex their arms at the elbow.

Explain that you are going to drop a box into their outstretched hands and that you require them to keep their elbows at right angles; in other words you drop the box into their hands and they respond by returning the hands to their original position.

Demonstrate the capabilities of the muscle spindle apparatus to respond to changes in muscle tension by dropping the differing boxes into the subject's hands and lead a discussion on how quickly the brain detects the change in stimulus intensity and adjusts the muscle tension.

Repeat the demonstration using a second subject who is blindfolded.

Task 2

Read through the following information, answering the questions that are posed in the spaces provided

Feedback is vital to learning and performance, and one of the most important forms of feedback is **kinaesthetic (intrinsic) feedback**.

Kinaesthetic feedback is provided by a group of internal sense organs called **proprioceptors**, which send nerve impulses to the brain about the position and movements of the body.

a What is intrinsic feedback?

Feedback from within the performer from their proprioceptors

b During which stage of learning is the performer most likely to be able to use intrinsic feedback?

Autonomous stage

There are **Golgi tendon organs**, which are found at the junction of tendons and muscles. These are sensitive to the force of a muscle's contraction, and they send this **sensory** information to the brain.

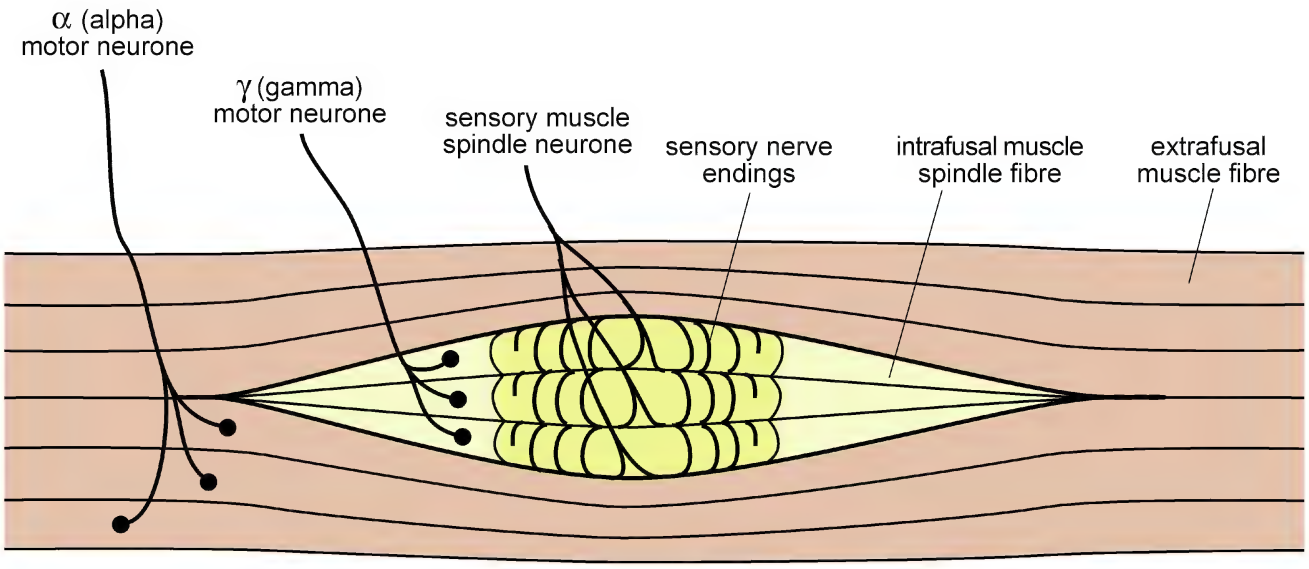
The ligaments surrounding joints also contain nerve endings or receptors that are sensitive to movements, so that actions can be corrected during performance. These receptors are vitally important in situations where maintaining balance is needed.

Changes in the length of muscles and the rate of change of muscle length, are sensed by receptors called **muscle spindles** that lie within the muscle itself.

Task 2 *continued*

Each muscle spindle consists of three modified muscle fibres (**intrafusal fibres**), wrapped up in a connective tissue skin (**the capsule**).

The intrafusal fibres lie within the normal muscle fibres (**extrafusal fibres**), and are supplied with both motor and sensory neurones. See the following diagram:



c What is the essential role of the muscle spindle apparatus?

They detect changes in the length of muscle fibres, and the rate of change of the length of the fibres

Muscle spindles are involved in the following processes: the detection of how contracted a muscle fibre is (**state of contraction**); the anticipation of how much of a contraction the muscle is going to need; the fine or delicate control of muscle contraction.

d What are the three functions of the muscle spindle apparatus

Detection of state of contraction; anticipation of muscle loading; fine control of muscle contraction

Task 2 *continued*

Whenever a muscle is stretched or shortened, the pull felt by the extrafusal fibres surrounding the muscle spindle apparatus is transferred to the intrafusal fibres, and thus the muscle spindle is similarly stretched or shortened (see diagram).

Thus, when a muscle is contracting and an additional load is added, the increased tension that occurs in the extrafusal fibres is transferred to the intrafusal fibres, and corresponding nerve impulses sent to the brain informing it that the load has increased. The brain responds by increasing the tension within the appropriate muscles to keep the limbs in the required position.

Whenever muscles change their length, the sensory nerve endings within the muscle spindle report the changing condition of that muscle back to the brain, so that appropriate adjustments in muscle contraction can be made. This is how the muscle spindles detect the state of contraction of muscles.

e Explain in your own words how the muscle spindle apparatus detects the state of contraction of muscles

Additional tension within muscle fibres is transferred to the intrafusal fibres of the muscle spindles which send corresponding nerve impulses to the brain providing information about the change in tension

Task 3

Use the same concept as in Task 1, but provide 3 boxes, one that is empty (light weight), one that is a third full of paper (heavy), and third that is also empty (light).

Explain to a subject that you are going to repeat the previous demonstration, but that each box will be getting progressively heavier, and that you are demonstrating that the response of the spindles is just as quick whatever the load involved (sic).

Drop the first box into the subject's hands. get the class to note the response. Now drop the second box and note the response.

Make a great play of attempting to lift the third box (empty!), to give the impression that it is very heavy (acting classes may be obtained through the performing arts department!), and drop it into the subjects hands

The usual response of the student is to anticipate a heavy load and use too much force to 'catch' the box, and it flies up into the air.

Follow the demonstration with a discussion of what has happened in terms of anticipating the tension required by the muscles (pre-setting the load).

Task 4

Read through the following materials and answer the questions provided.

Muscle spindles are also involved in the anticipation of how much strength a muscle is going to need for a certain action (**muscle loading**). The obvious thing being that you need to use a different force at different times for the same action.

The muscle pre-sets the tension within itself, based on information held in memory, a process known as **gamma bias**. The muscle spindles can then adjust the tension required, by feeding back sensory information to the brain and causing immediate adjustments.

For example, consider what happens when you are waiting, with your arm bent at the elbow, hand extended and palm uppermost, for a box to be placed in your hands.

If that box is unexpectedly heavy, your forearm starts to drop, which stretches the muscle fibres in your biceps brachii, which in turn stretches the muscle spindles.

In response to that stretch, the sensory muscle spindle neurones send impulses to the brain, and a corresponding contraction of the biceps occurs, overcoming the stretch.

What is observed in practice is that there is a fractional drop of the forearm before correct tension is restored to the muscles involved.

When the weight in the box is lighter than expected, the loading set by the muscle spindles is too great, and there is a large muscle contraction where only a small one is necessary, leading to the actions observed.

a Describe the concept of muscle loading in your own words.

Muscle loading is the setting of an appropriate tension within the muscle through gamma bias based on experience

Skeletal muscle can be stimulated to contract either directly, via nerve impulses from the brain and spinal cord (**alpha motor neurones**), or indirectly via the muscle spindles.

In indirect control, other motor neurones, the **gamma motor neurones**, stimulate the muscle fibres within the muscle spindles (**intrafusal fibres**) to contract.

When these contract, the sensory stretch receptor is further stretched, which causes a reflex contraction of the normal (**extrafusal**) muscle fibres, via the alpha motor neurones.

Task 4 *continued*

This type of control of muscle contraction is slower than the normal system, but does give finer control, and also adds force to a normal contraction.

b Describe how muscle spindles are involved in the fine control of muscles.

Use of gamma motor neurones as well as alpha motor neurones gives finer control of movements

c Describe how muscle spindles are involved in providing extra forceful contractions of muscles.

Use of gamma motor neurones as well as alpha motor neurones gives a greater force of contraction

Task 4 *continued*

One very important aspect of training and competition is the need to warm-up, and at the same time increase flexibility. In fact flexibility training should be part of every training session, not just part of a warm up.

If a muscle is suddenly stretched during such exercises, the muscle involved almost instantly contracts to resist the stretch. This is the protective **stretch reflex**.

The commonest demonstration of this phenomenon is the **knee-jerk reflex**, where, if the legs are crossed (stretching the quadriceps muscle), and the tendon attached to the quadriceps muscle (patella tendon) tapped with a reflex hammer, the quadriceps are stretched even further.

The intrafusal fibres of the muscle spindles detect the sudden extra stretch caused by the tap and send nerve impulses to the spinal cord, and a corresponding nerve impulse is sent via the alpha neurones to the extrafusal fibres, causing the quadriceps muscle to contract, and the lower leg is seen to suddenly jerk.

At the same time, inhibitory impulses are sent to the antagonistic muscles, in this case the hamstrings, causing them to relax, to allow the movement to occur.

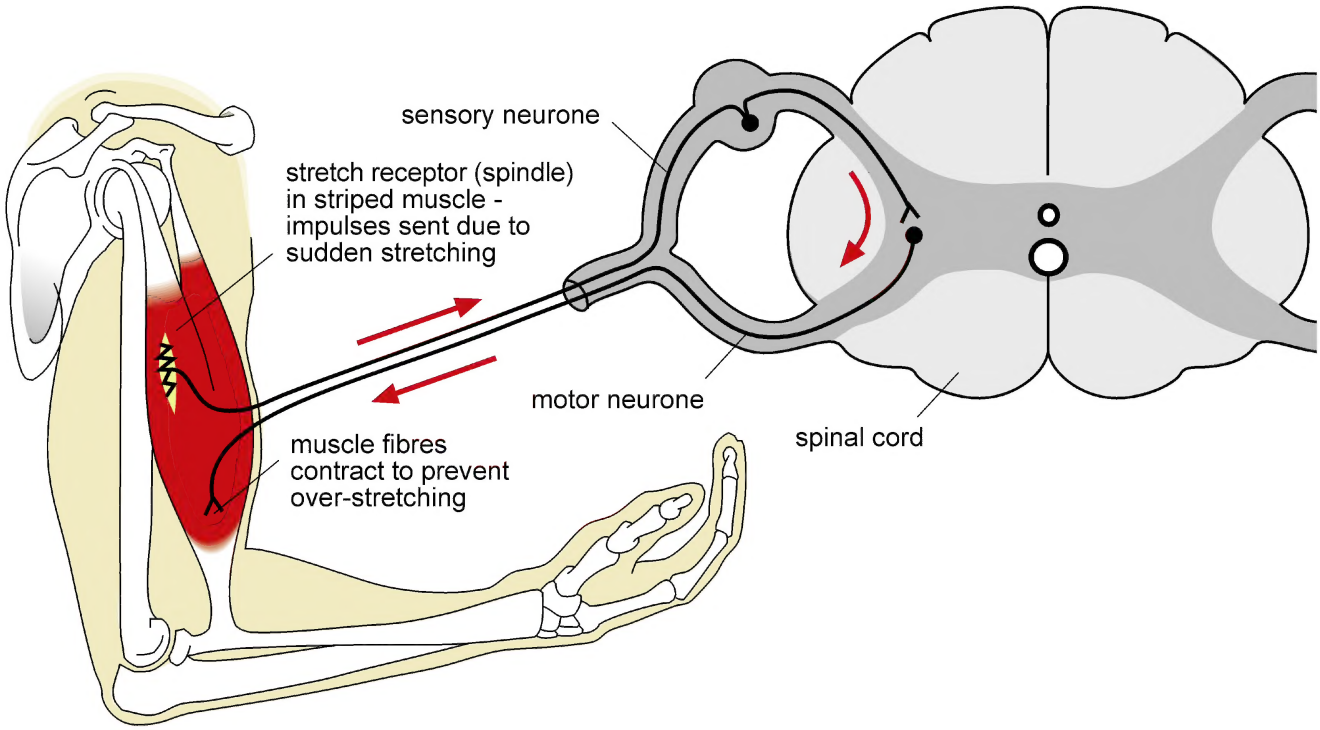
d What is this phenomenon called?

reciprocal inhibition

Task 4 *continued*

Contraction of the quadriceps stops the stretch on the muscle, thus removing the stimulus for the reflex, and the muscle quickly relaxes. The stretch reflex prevents over-stretching of a muscle and is thus a protective mechanism.

The same reciprocal inhibition acts in all voluntary muscles. See below:


sensory neurone
stretch receptor (spindle) in striped muscle - impulses sent due to sudden stretching
motor neurone
spinal cord
muscle fibres contract to prevent over-stretching

e Describe the stretch reflex.

Protective mechanism where sudden stretching of a muscle is detected by muscle spindle apparatus, which leads to a reflex contraction of the muscle being stretched

Task 4 *continued*

Use is made of the stretch reflex of muscle spindles during plyometric training. Plyometric training involves jumping and bounding exercises where there is an eccentric contraction of a muscle followed by a concentric contraction.

f Distinguish between eccentric and concentric muscle contractions.

Muscles lengthen while exerting tension during eccentric contractions, and shorten (contract) while exerting tension during concentric contractions

Plyometric training uses the body's mass and gravity to prestretch the agonist muscle. The eccentric prestretch is thought to activate the gamma neurones of the muscle spindle and so provide additional contractile force via the stretch reflex.

g Explain how gamma neurones produce extra contractile force.

When stretched, the intrafusal fibres of the muscle spindle apparatus send sensory impulses to the spinal cord which result in contraction of the intrafusal fibres via gamma neurone stimulation. This is in addition to the 'normal' alpha stimulation of the muscle fibres and therefore produces a stronger contraction

Task 4 *continued*

The stretch reflex is also involved in Proprioceptive Neuromuscular Facilitation (PNF) forms of stretching. In practical terms, PNF involves a stretch being undertaken to the limit of the range of motion involved.

Once this limit has been achieved, the stretched muscle is contracted isometrically and held in a state of tension for approximately 6 seconds and then relaxed.

During this period the muscle spindles involved would be sending fewer impulses to the brain as the effects of the isometric contraction persist. Thus the strength of the stretch reflex becomes diminished through habituation, and the range of motion of the stretch can be increased without the stretch reflex preventing such actions.

h Explain the role of the stretch reflex in PNF stretching.

In PNF stretching, the muscle spindle reflex is reduced through habituation during a held stretch and isometric contraction of the agonist, thus reducing the inhibitory effect and permitting increased range of movement